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A hybrid packet-circuit switched router for optical network on chip ☆

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ABSTRACT

The increasing number of Intellectual Property (IP) cores challenges the traditional electrical Network on Chip (NoC). Silicon nanophotonics becomes a leading technology because of offering several benefits for NoC. Also, On-chip services, including guaranteed service and best-effort service, have different traffic characteristics. This has an important influence on the performance of NoC. This paper proposes a hybrid packet-circuit switched router for optical Network on Chip (ONoC). It can support optical circuit switching (OCS) and optical packet switching (OPS) in parallel and simultaneously, in order to optimize the performance of the network with both services. According to the simulation results, the proposed architecture achieves lower latency and higher throughput than the traditional architectures in the same network scale.

1. Introduction

With the integration density increment of a single chip, the recent development in the chip design indicates a progress towards the multi-core era. As the number of Intellectual Property (IP) cores integrated in a single chip increases, the performance of the Network on Chip (NoC) is being limited in aspects of power consumption, data latency, throughput, and so on. The global interconnect becomes a critical determinant of the entire network performance, because it plays an important role in the interconnection of IP cores. There is an increasing need for the traditional electrical interconnect to meet the speed and highly-scalable throughput in the network with large numbers of IP cores. However, the electrical interconnect performs not so well in the areas of power efficiency and performance scalability [1]. Also, there is a reliability problem [2].

One solution to solve these aforementioned bottlenecks is the optical interconnect, with higher speed of signal propagation, higher bandwidth density and lower power dissipation. Based on the Silicon-on-Insulator (SOI) platform, many optical devices that can be applied in NoCs have significant advances [3–9]. This makes the optical interconnect an attractive technology. As a result, based on silicon photonics, several architectural designs for NoCs have been proposed by various research groups.

The services in NoCs can be roughly classified into two categories: the guaranteed service and the best-effort service. The traffic of different services has different characteristics separately. The guaranteed service needs to reserve some resources to guarantee the throughput, and most traffic of the guaranteed service is longer in the length and more continuous in the time. The best-effort service does not require the reservation of resources to guarantee the performance, and the traffic of the best-effort service is generally short in the length and burst in the time. The design of the router architecture is mainly dependent on the traffic characteristics in the chip. Thus, a router that can satisfy the requirements of two categories of traffic at the

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same time would present some advantages in terms of delay, throughput and cost. Most of the current designs utilize only one kind of switching mechanisms, optical circuit switching (OCS) or optical packet switching (OPS). However, if the traffic of different services is handled with the same switching scheme, the network efficiency may be low and the communication cost can be high.

In the optical Network on Chip (ONoC), OCS can process the traffic of the guaranteed service effectively, but it is not so effective for the best-effort service [10]. OPS is more efficient for the traffic of the best-effort service, but it is inefficient for the guaranteed service. To meet the traffic requirements of the guaranteed service and best-effort service simultaneously, we present a hybrid switched router for ONoC. The proposed router processes the traffic of different services separately, by separating the traffic in different wavelengths. Thus, it can support OCS and OPS mechanisms in parallel.

The rest of the paper is organized as follows. Section 2 gives a brief introduction of the current related works in ONoCs. Section 3 gives a detailed description of the proposed router, including the architecture, the schemes of switching, the flow control, and the contention resolution. In Section 4, we analyze the performance of optical power and loss, and evaluate the network performance with simulations. Also, a performance comparison of different architectures is made. Finally, conclusions are presented in Section 5.

2. Related works

The optical interconnect exhibits better performance than the electrical alternative. Several ONoC architectures composed of nanophotonic devices have been proposed. Cianchetti et al. [11] propose a hybrid electrical/optical network called Phastlane. The router of the network can optically transmit packets several hops in the network, with electrical buffers to solve the blocking problem. Joshi et al. [12] propose a network named as Clos. It uses the silicon-photonic technology for the global on-chip communication. This exploits multiple stages of small routers to form a larger non-blocking network. Pan et al. [13] present a hierarchical topology based on clusters, Firefly. In this network, the electrical interconnect is used for the local intra-cluster communication and the optical crossbars for the global inter-cluster communication. The global crossbar is implemented by the bus waveguides. Shacham et al. [14] propose a 2D photonic NoC architecture, consisting of an electrical network and a photonic network. The control information is handled in the electrical network, whereas the data transfer occurs in the photonic network. Before the data transmission being processed, an electrical path setup packet is routed in the electrical network to reserve the resources of the optical network from the source to the destination. This is for establishing an optical data path. After the success of the path establishment, the data transfer begins. In the end, a packet is sent to tear down the established path. Corona, a 3D many-core optical architecture targeted for a 16 nm process in 2017, is developed by Vantrease et al. [15], with a photonic crossbar interconnecting 256 cores in 64 four-core clusters. The crossbar is realized by numerous many-writer single-reader buses, combining with wave-division-multiplexing (WDM) to provide higher bandwidth. To resolve the conflict, a token-based arbitration scheme is used to allocate the available channels to clusters. Kirman et al. [16] present a hierarchical opto-electrical system based on the shared ring-bus to support the snoopy cache coherence in future Chip Multiprocessors (CMPs). The total 64 cores are organized in four nodes, each with four cores and a shared L2 cache communicating electrically. The bus architecture is employed for the inter-node communication. Batten et al. [17] develop a new processor-memory network in mesh topology based on an opto-electrical global crossbar, in order to provide the performance improvement in the manycore bandwidth. Miller et al. [18] present a tiled multicore architecture based on snake-shape waveguides, aiming at the technology node of 11 nm in 2019 with at least 1000 cores. Two networks exist, the electrical network for the short-range communication and the optical network for the global communication. Kirman and Martìnez [19] propose a design for ONoCs, composed of passive optical wavelength routers. The routers are incorporated with the wavelength-based routing algorithm and oblivious routing algorithm to construct an all-optical network for CMPs. Koohi et al. [20] present an all-optical NoC in a new proposed regular and scalable topology, named as 2D-HERT. It employs a new kind of optical switch called WaROS. Li et al. [21] introduce an optical on-chip network, including a broadcast/multicast subnetwork for the latency-critical communication traffic and a circuit-switching subnetwork for the throughput-critical communication traffic. This optimizes the performance of the latency and throughput. Brière et al. [22] study an ONoC based on the λ-router. The switching is completed depending on the wavelength value of the optical signal. Pasricha et al. [23] propose an on-chip communication architecture based on an optical ring bus for the next generation Multi-Processor Systems-on-Chips (MPSoCs). The optical ring interconnects are used to replace the global pipeline electrical interconnects. This can overcome the bottleneck of electrical interconnects. Wu et al. [24] present a unified inter/intra-chip optical network, called UNION. It utilizes a hierarchical optical network to separate the inter-chip communication traffic from the intra-chip communication traffic. The local processor cluster is connected by electrical interconnects while the communication among the clusters is done by optical interconnects. A centralized control method is used to configure paths. This is a novel optical circuit switching method. Beux et al. [25] propose the Optical Ring Network-on-Chip (ORNoC) which is contention-free. Electrical interconnects are used in the intra-cluster/intra-layer, while optical interconnects are utilized in the inter-cluster/inter-layer. The same wavelength may be used in a single waveguide, providing wavelength sharing.

Compact optical routers are essential components for ONoCs. Biberman et al. [26] design a nonblocking four-port photonic router for ONoCs employing eight microring resonators. The switch-state of the microring resonator is configured by using direct-current resonance tuning. For different applications in the photonic NoC, Ji et al. [27,28] propose a four-port optical router and a five-port optical router, based on microring resonators. Both of the routers are non-blocking. The microring resonators are in the same radius, tuned through the thermo-optic effect. Tan et al. [29] propose a generic wavelength-routed optical router (GWOR) which is based on microring resonators and appropriate for passive networks. Routing in the proposed router is completed by using different signal wavelengths and microring resonators with different geometries. Hu et al. [30] design a wavelength-selective nonblocking four-port silicon optical router. Signals are routed according to their particular wavelengths. Passive microring resonators are placed at appropriate waveguide crossings to form fixed paths between input and output ports. Cianchetti et al. [31] propose a novel optical router for future CMPs. It utilizes a predecoded source routing algorithm to route packets, a localized router control to eliminate the latency of OCS path establishing time, and the on/off flow control to avoid dropping packets in the previous proposed architecture.

Most of these designs utilize either the circuit switching mechanism or the packet switching mechanism, not efficient to support both the guaranteed service and the best-effort service.

3. Proposed hybrid switched router architecture

3.1. Microring resonator-based switching elements

The optical router, responsible for routing messages from the input port to the output port, is an essential part of ONoC. The microring resonators are important building blocks of an optical router. The microring resonator works by changing the resonant wavelength through electric-optic or thermo-optic effects. This correspondingly changes the state of the microring resonator-based switching element [28]. Fig. 1(a) and (b) show the two states of the microring resonator-based switching element. When the switching element is in the off-state, it is resonant at the wavelength of λ_{OFF}. An input optical signal with the wavelength of λ ($\lambda \neq \lambda_{OFF}$) propagates from the input port to the through port. When the switching element is in the on-state, the resonant wavelength is changed from λ_{OFF} to λ_{ON}. An input optical signal with the wavelength of λ ($\lambda \neq \lambda_{ON}$) will couple into the microring resonator from the input port and transfer to the drop port.

3.2. Router architecture

Fig. 2 depicts the architecture of the proposed $N \times N$ optical router, mainly including OPS Control Unit, OCS Control Unit, Demultiplexer Unit, Buffer Unit, Multiplexer Unit, Optical Crossbar and Flow Control Unit. The number N depends on the network topology. For example, for a 2D mesh network, N is equal to 5. The router supports both OCS and OPS, mainly controlled by the OCS Control Unit and the OPS Control Unit. Wavelength λ_1 is employed to send messages in OCS, while λ_2 for OPS.

Each input port connects with the OPS Control Unit to provide the necessary routing information for the OPS Control Unit. The OPS Control Unit implements the routing computation and arbitration. The routing algorithm to be used is selected according to the network feature. For example, the *XY* routing algorithm is employed in the 2D mesh network, owing to its simplicity and being deadlock-free. Each input port also connects to the Demultiplexer Unit. The Demultiplexer Unit enables the message to be buffered or to go forward, which is controlled by the OPS Control Unit. One output of the Demultiplexer Unit is connected to the Buffer Unit, and then to the Multiplexer Unit. The other one is directly connected to the Multiplexer Unit. The structures of the Demultiplexer Unit and Multiplexer Unit used in the proposed router are shown in the right illustration of Fig. 2. The Demultiplexer Unit, Buffer Unit, and Multiplexer Unit are set by the OPS Control Unit according to the results of routing computation and arbitration. The microring resonator based Optical Crossbar connects the Multiplexer Units with the output ports, responsible for forming different paths between different input ports and output ports. It is controlled by the OPS Control Unit and the OCS Control Unit corporately. The OPS Control Unit manages the microring resonators with on-state wavelength λ_2 in appropriate locations of the Optical Crossbar, based on the computation and arbitration results. The OCS Control Unit is responsible for routing the electrical control messages in OCS. According

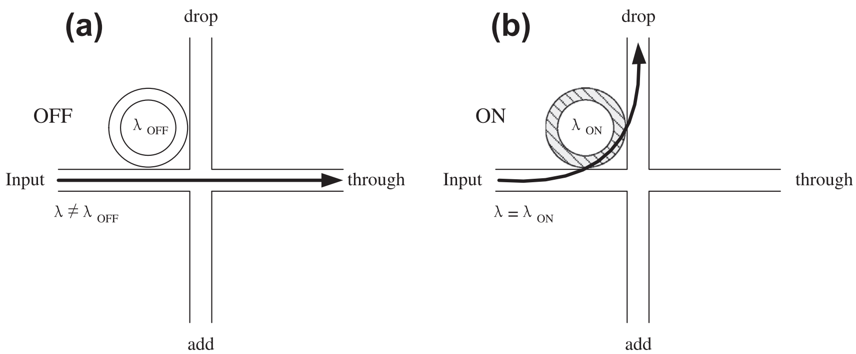

Fig. 1. (a) Switching element in the off-state. (b) Switching element in the on-state.

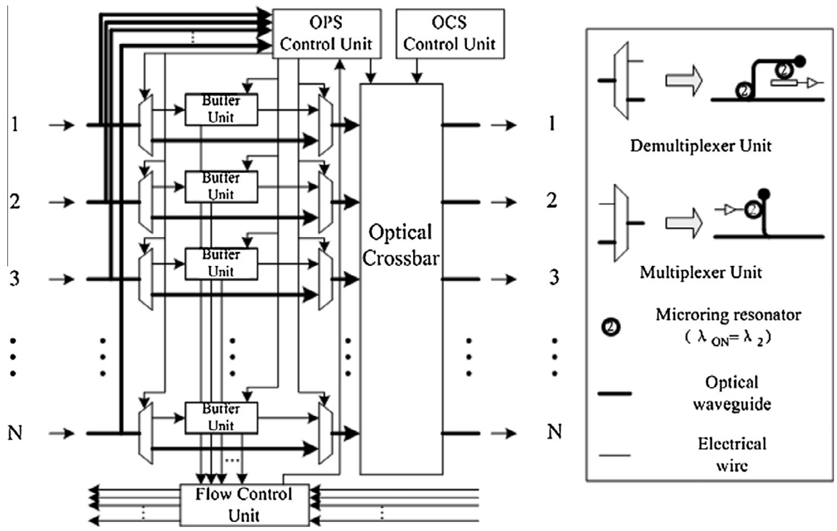

Fig. 2. The proposed router architecture.

to the results of routing computation, the OCS Control Unit manages the microring resonators with on-state wavelength λ_1 in the Optical Crossbar, so as to set up an optical path in advance. The Flow Control Unit implements the on/off flow control function. It is responsible for detecting the input electrical buffering state of the local router, in order to send the flow control signal to the upstream router. It also receives the flow control signal from the downstream router to notice the OPS Control Unit to take the buffer state into consideration.

There is no optical buffer to store packets directly in the optical domain at present. When two or more packets need to compete for the same output port at the same time in OPS, there will be a conflict. Thus, the contention resolution scheme is needed, since only one packet can be sent to an output port at any time. If a packet with wavelength λ_2 is failed in the contention for the desired output port, the OPS Control Unit turns on the microring resonators in the corresponding Demultiplexer Unit. The packet will be received electrically and buffered in the Buffer Unit, waiting for the next chance to be sent. When the buffered packets and the new coming packets are contending for the same output port, the buffered ones have higher priority. Once the buffered packets are permitted to be sent, they are converted back to the optical signal again and routed in optical routers until the communication destinations.

As the most important element in the proposed router, the microring resonator based Optical Crossbar consists of waveguides and two groups of microring resonators. One group with on-state wavelength λ_1 is used for OCS and the other one with on-state wavelength λ_2 is used for OPS. The off-state wavelength of two groups is neither λ_1 nor λ_2. *N* ports correspond to the *N* ports of the router respectively. The Optical Crossbar can operate non-blocking switching, enabled by the appropriate layout and state change of microring resonators in two wavelengths. The Optical Crossbar is controlled via the electrical signals generated by the OPS Control Unit and OCS Control Unit. An example of a 5×5 Optical Crossbar is shown in Fig. 3. It can be used for a mesh topology. It consists of fifteen waveguides, 21 microring resonators with on-state wavelength λ_1 and 24 microring resonators with on-state wavelength λ_2.

Consider two messages in wavelength λ_1 and λ_2 being injected in port 1 and going to port 4, as shown in Fig. 3. The three microring resonators with on-state wavelength λ_1 from port 1 to port 4 are numbered C1, C2, and C3 in order. They are set to the off-state, on-state and off-state respectively. Hence, the message in wavelength λ_1 will make the turn at C2. The route is shown as the OCS signal path. Similarly, we number the microring resonators with on state wavelength λ_2 P1, P2, P3, and P4 from port 1 to port 4. Before the transmission of the message in wavelength λ_2, microring resonators P1 and P3 are set on, and the other two are set off. Then, the message in λ_2 will be coupled into microring resonator P1, bypass P2, be coupled into P3, and pass through P4. The route is shown as the OPS signal path.

3.3. Switching mechanism

The proposed router architecture supports two switching mechanisms that refer to OCS and OPS. The choice of the switching mechanism for message transmission is determined by the source node.

Once the generated traffic requires the guaranteed service, OCS is adopted to deliver the message. An electrical control packet, named as a path setup packet, is routed by the OCS Control Unit to set up a data path for the transmission of optical data in optical routers. After the success of the path setup, the optical data will be transported along the path without interruption. Thus, OCS inherently offers the guaranteed throughput.

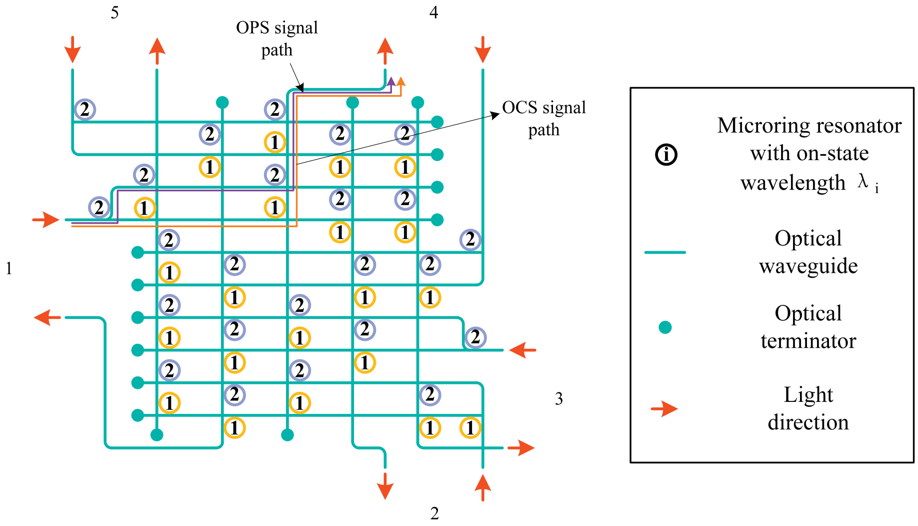

Fig. 3. The optical crossbar used for a mesh topology.

Besides OCS, the other switching mechanism, OPS, is employed to deliver the traffic demanding the best-effort service. In OCS, the data and control information are separated, while in OPS the routing information is included inside optical packets. After generated by the communication source, optical packets are routed in optical routers. Meanwhile, there is no need of resource reservation in advance. Also, optical packets are routed and switched optically in sub-ns scale. Compared with OCS, the resources are not occupied for a long time, which increases the resource utilization. The flow control mechanism is needed due to the limited buffering space. Packets in upstream routers are allowed to send only when there is enough space in the current router. In the proposed router architecture, the on/off flow control mechanism is implemented because of its lower hardware overhead and less upstream signaling in certain cases compared to the credited-based flow control mechanism. The flow control function uses the Flow Control Unit, together with special wires inside the current router or connected with adjacent routers.

4. Performance evaluation

4.1. Performance analysis of optical power and loss

It is assumed that an off-chip laser source provides the optical sources. From the generation of an optical packet to the communication completion, the packet will go through some optical devices, for example, waveguides and microring resonators. The insertion loss is introduced in each of them. Table 1 shows the related optical loss values. With the values in Table 1, the optical loss between different ports can be calculated. The results of Fig. 3 are listed in Table 2. Using the results in Table 2, the total insertion loss along a path can be calculated.

Since the proposed router architecture is based on microring resonators and waveguides, the waveguide crossing is inevitable and it can introduce a lot of insertion loss. As shown in Table 1, the loss of waveguide crossing in the single-layer integration is 0.05 dB. Using this value, we calculate the insertion loss of waveguide crossing between different ports in the OCS mechanism. The minimum is 0.1 dB, while the maximum can reach 0.7 dB. This kind of insertion loss can account for a large part of the total loss when the packet transmits through a long path. A possible method to eliminate the optical power loss associated with in-plane waveguide crossings is utilizing two waveguide layers. However, the interlayer coupling is weak, which also introduces high insertion loss. This method may be available in the future by appropriately selecting the inter-layer material and thickness [33].

Table 1
Optical loss parameters [32].

Component	Value	Unit
Waveguide propagation	0.5	dB/cm
Waveguide bending	0.005	dB/90°
Waveguide crossing	0.05	dB
Passing by a microring resonator	0.05	dB
Coupling with a microring resonator	0.5	dB
Receiver sensitivity	−20	dBm

Table 2
The insertion loss of the proposed router in a 5×5 scale.

λ_2 Loss (dB)	λ_1 Loss (dB) Output				
Input	3	2	1	4	5
3	–	0.66 1.215	0.865 1.42	1.11 1.565	1.3 1.755
2	1.105 0.66	–	1.315 0.87	1.81 1.265	1.95 1.405
1	1.305 1.86	1.16 1.715	–	0.86 1.315	0.65 1.105
4	0.81 1.355	0.865 1.41	1.07 1.615	–	1.155 1.6
5	1.41 1.955	1.265 1.86	1.12 1.665	0.715 1.16	–

Meanwhile, the optical power that will reach the receiver of the destination IP core must maintain above a threshold, i.e., receiver sensitivity, to make sure that the packet is received properly. Therefore, the laser power must be kept above a minimum level which can cover both the total insertion loss and the receiver sensitivity. This minimum laser power depends on the worst-case optical loss along a single path. The worst case occurs when the optical packet goes through the longest path between the source and the destination, resulting in the maximum insertion loss. The minimum laser power can be estimated using the following equation:

$$P_{min\_laser}^{dBm} = P_{receiver}^{dBm} + P_{total\_loss\_1}^{dB} + P_{total\_loss\_2}^{dB}, \tag{1}$$

where $P_{min\_laser}^{dBm}$ is the minimum laser power estimation, $P_{\text{receiver}}^{dBm}$ is the receiver sensitivity, $P_{total\_loss\_1}^{dB}$ is the total insertion loss of message in wavelength λ_1 along the communication path, and $P_{total\_loss\_2}^{dB}$ is the total insertion loss of message in wavelength λ_2 along the communication path.

In this paper, we consider the minimum laser power needed in Fig. 4 for example. Fig. 4 illustrates the basic ONoC architecture in 8×8 scale. The architecture consists of two layers, IP cores layer and photonic network interconnect layer. The IP cores layer is comprised of IP cores, and the photonic layer is composed of optical routers. There are four situations where the message experiences the longest path in Fig. 4: from (0,0) to (7,7), from (0,7) to (7,0), from (7,7) to (0,0), and from (7,0) to (0,7). Using the network simulator, OPNET [34], we simulate the insertion loss respectively, including $P_{total\_loss\_1}^{dB}$ and $P_{total\_loss\_2}^{dB}$, and the results are shown in Fig. 5. It is obvious that the maximum $P_{total\_loss\_1}^{dB}$ occurs when the message transmits from (0,0) to (7,7), and the maximum $P_{total\_loss\_2}^{dB}$ occurs when the message transmits from (0,7) to (7,0). The values are 24.91 dB and 26.89 dB respectively. Germanium photodetectors each have a responsivity of 1 A/W, and the receiver circuits each have a sensitivity of -20 dBm for error-free operation [32] in which bit error rate (BER) is lower than 10^{-12}. Thus, the minimum laser power estimation is about 15.136 mW according to Eq. (1).

4.2. Network performance

In this section, we evaluate the network-level performance of the proposed router in 4×4 and 8×8 mesh networks through simulations. As the tendencies of both cases are similar, the results of the 8×8 mesh network are given. In order

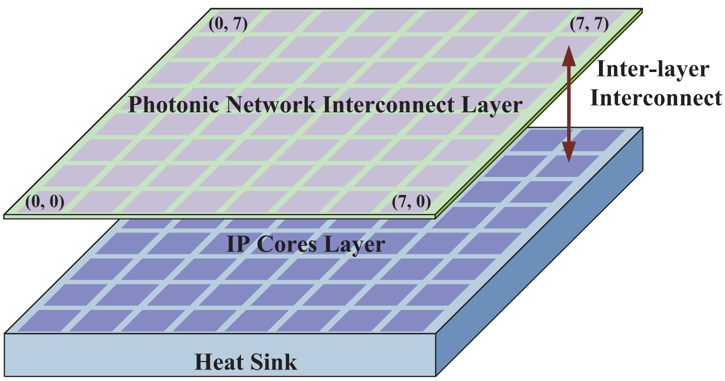

Fig. 4. 8×8 Mesh based ONoC.

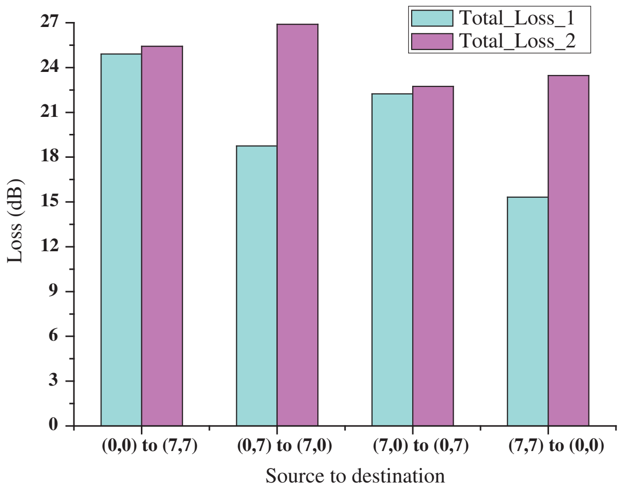

Fig. 5. Total loss of the longest paths.

to show the performance improvement, two traditional architectures in the same network scale are simulated. The simulation is conducted by using OPNET. The frequency of the electrical router is assumed to be 1 GHz, which is popular in NoCs. The bandwidth of optical interconnect is assumed to be 12.5 Gb/s [35], which can be realized by the microring resonator based nanophotonic technology. In consideration of the power efficiency and the ratio of OPS traffic, the electrical buffer per input port of the proposed router is assumed to be 64 bits. The packets injected into the network are subject to Poisson distribution over time.

The architectures are evaluated in terms of End-to-End (ETE) delay and throughput under the given injection rate of packets which is called offered load. ETE delay is defined as the average delay of a packet from generation to destruction in the network, including injection time, propagation time, processing time and so on. Throughput is defined to be the number of packet bits received correctly by the communication destinations per second.

We evaluate the performance of the network with the proposed router in Uniform traffic patterns under different factors of the OCS traffic, for example, different ratios in the communication and different optical packet lengths. From the simulation results, it can be found that different situations have a similar tendency.

Fig. 6 shows the ETE delay and throughput performance of the proposed architecture under different ratios of OCS traffic in the Uniform traffic pattern. The OCS packet length is 2048 bits and the OPS optical packet length is 32 bits. We can see that the tendencies of the ETE delay, as well as those of the throughput, are similar under different ratios except that the values are a little different under the same offered load. Besides, the higher the ratio is, the larger the ETE delay gets and the lower the throughput becomes. It is because that the traffic of OCS is more when the ratio is higher, and more time is needed to transmit optical packets of OCS.

Also, we simulate the performance of the proposed architecture under different optical packet lengths of OCS traffic, with the ratio of OCS traffic 10%. The result is shown in Fig. 7. It can be found that the tendencies under different optical packet lengths of OCS traffic are similar except a little difference in numerical size under the same offered load. Moreover, the longer

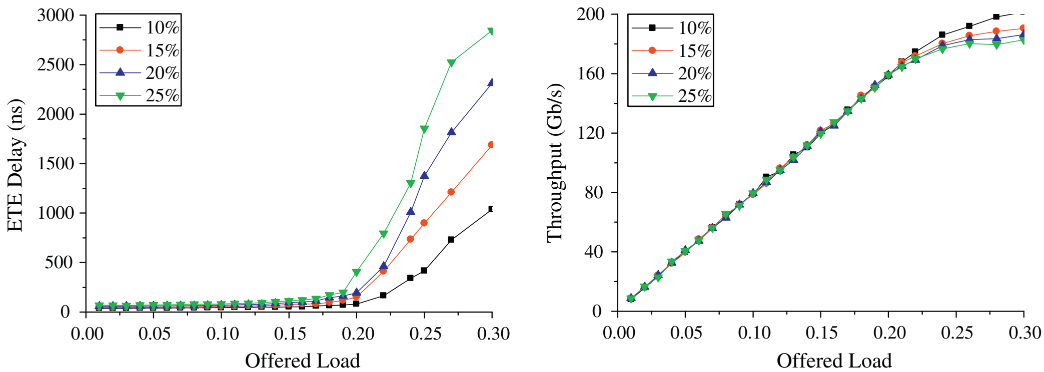

Fig. 6. ETE delay and throughput performance of the proposed architecture under different ratios of OCS traffic.

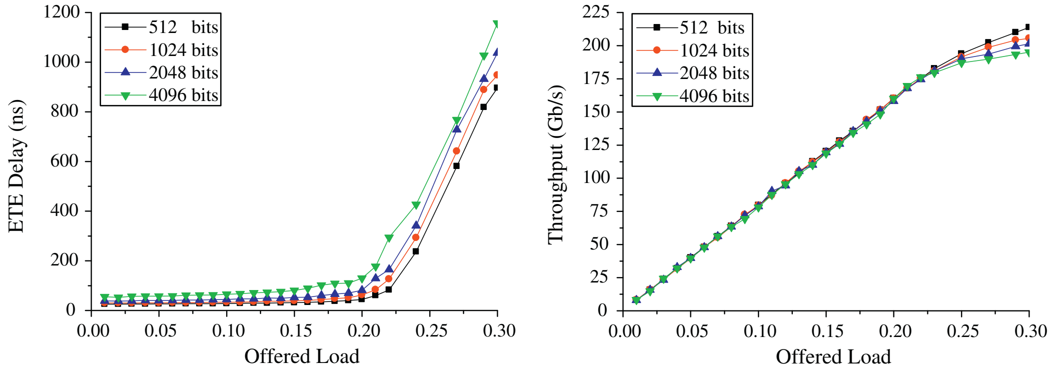

Fig. 7. ETE delay and throughput performance of the proposed architecture under different optical packet lengths of OCS.

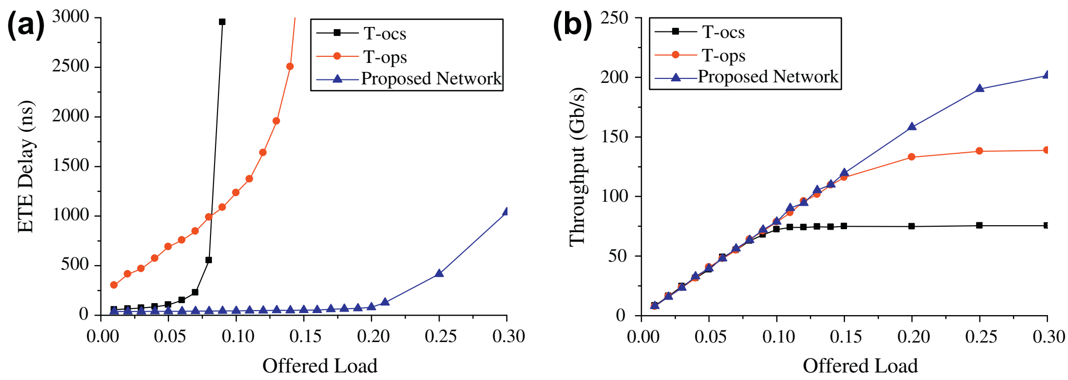

Fig. 8. (a) ETE delay for Uniform traffic. (b) Throughput for Uniform traffic.

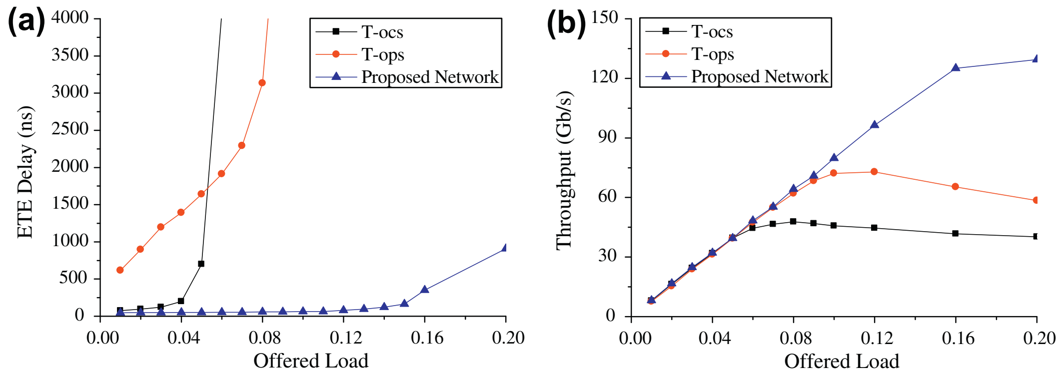

Fig. 9. (a) ETE delay for Bit Complement traffic. (b) Throughput for Bit Complement traffic.

the packet is, the larger the ETE delay is and the lower throughput gets. The reason is that it takes longer time to transmit the optical packet of OCS, which accounts for a large part of the ETE delay.

We compare the proposed architecture with the traditional optical-electrical hybrid circuit switching network (named T-ocs for short) [14] and optical packet switching network based on conversion between optical pattern and electrical pattern at each router (named T-ops for short). They also utilize the *XY* routing algorithm.

We evaluate three synthetic traffic loads [31]: Uniform, Bit Complement, and Transpose. It is assumed that 10% of the communication requires OCS, with the left served by OPS. Moreover, the optical packet length is 2048 bits in OCS and it is 32 bits in OPS [36]. The results of ETE delay and throughput versus offered load are reported in Figs. 8–10. No matter what kind of service, each of the two traditional architectures utilizes only one switching mechanism, while the proposed archi-

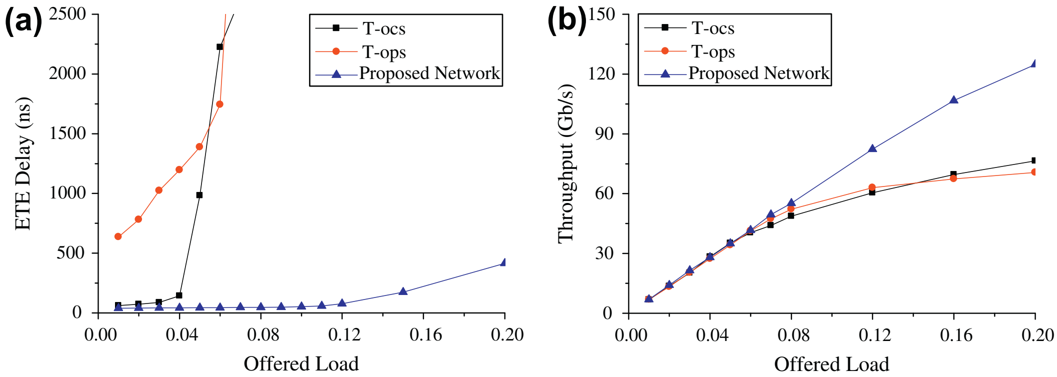

Fig. 10. (a) ETE delay for Transpose traffic. (b) Throughput for Transpose traffic.

tecture is able to support OCS and OPS in parallel, achieving lower latency and higher throughput. Take the simulation results in Fig. 8 as an example. When the offered load increases to 0.2, the performance of the proposed architecture will come down significantly, the ETE delay rising up sharply and the throughput becoming almost constant. This is because that the network becomes congested and saturated, with more packets injected into the network. The point from which the performance comes down is called saturation point. However, the saturation points of T-ocs and T-ops, which are much lower than that of the proposed architecture, are around 0.09 and 0.14 respectively in the Uniform traffic pattern. When the offered load is 0.07, the ETE delay of T-ocs and T-ops are 5.42 times and 20.15 times that of the proposed network, respectively. When the offered load is 0.25, the throughput of the proposed network is 2.52 times and 1.38 times that of T-ocs and T-ops respectively. Thus, we can conclude that the performance of the proposed network is improved.

5. Conclusions

In this paper, we have proposed a hybrid packet-circuit router for ONoC. The proposed router can support the hybrid switching mechanism with respect to guaranteed service and best-effort service. Employing the OCS Control Unit and the OPS Control Unit, it can coordinate OCS and OPS at the same time with the support of WDM technology. The work of the switching part is explained based on an example of a 5×5 Optical Crossbar. The hybrid switching mechanism is designed based on the proposed architecture. We analyzed the insertion loss of the proposed router in a 5×5 scale in consideration of the basic optical loss. On this basis, the minimum laser power is analyzed and the situation in an 8×8 mesh based ONoC is considered. Meanwhile, the performance of the proposed architecture is evaluated. Simulation results show that for the proposed architecture in Uniform traffic patterns, the higher the ratio of OCS traffic is, the larger the ETE delay gets and the lower the throughput becomes; the longer the packet length of OCS traffic is, the larger the ETE delay is and the lower throughput gets. Moreover, when the proposed architecture is compared with two traditional architectures, it achieves better performance along with lower ETE delay and higher throughput under three different traffic loads: Uniform, Bit Complement, and Transpose. The proposed router is promising considering the two different services. Our future work includes the study of optical buffers which can improve the speed of switching further, and the optimization methods of the proposed architecture.

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