Crosstalk Noise and Bit Error Rate Analysis for Optical Network-on-Chip

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ABSTRACT

Crosstalk noise is an intrinsic characteristic of photonic devices used by optical networks-on-chip (ONoCs) as well as a potential issue. For the first time, this paper analyzed and modeled the crosstalk noise, signal-to-noise ratio (SNR), and bit error rate (BER) of optical routers and ONoCs. The analytical models for crosstalk noise, minimum SNR, and maximum BER in mesh-based ONoCs are presented. An automated crosstalk analyzer for optical routers is developed. We find that crosstalk noise significantly limits the scalability of ONoCs. For example, due to crosstalk noise, the maximum BER is 10^{-3} on the 8×8 mesh-based ONoC using an optimized crossbar-based optical router. To achieve the BER of 10^{-9} for reliable transmissions, the maximum ONoC size is 6×6. A novel compact high-SNR optical router is proposed to improve the maximum ONoC size to 8×8.

Categories and Subject Descriptors: B.7.0 [General]; C.5.4 [VLSI Systems]; C.1.2 [Processor Architectures]: Multiple Data Stream Architectures (Multiprocessors) - Interconnection architectures, parallel processors.

General Terms: Measurement, Performance, Design

Keywords: Optical network-on-chip, crosstalk, SNR, BER

1. INTRODUCTION

On-chip optical communication and integration technologies propose an attractive solution for MPSoC on-chip communication. The introduction of photonics to on-chip global interconnect structures can potentially capitalize on the unique advantages of optical communication. Several optical networks-on-chip (ONoC) architectures and optical routers are proposed based on optical waveguides and microresonators, and showed ultra-high capacity and low-power consumption [1][2][3].

Crosstalk noise is an intrinsic characteristic of photonic devices [4][5]. It is a potential issue in optical networks-on-chip (ONoCs). Crosstalk noise is the undesirable coupling among optical signals. During crosstalk, a small portion of the power from one optical signal is directed to another optical signal and becomes noise. Large crosstalk noise will lower signal-to-noise ratio (SNR) of an ONoC and cause high bit error rate (BER). BER is an important consideration in any communication system including ONoCs. It is defined as the percentage of bits that have errors relative to the total number of bits received during a transmission. For reliable data transmissions, BER is required to be lower than 10^{-9}. BER is directly affected by SNR, which is the ratio between signal power level and noise power level in ONoCs.

For the first time, this paper analyzed and modeled the crosstalk noise, SNR, and BER of optical routers and ONoCs. The analytical models for crosstalk noise, minimum SNR, and maximum BER in mesh-based ONoCs are presented. An automated crosstalk analyzer for optical routers is developed. We find that crosstalk noise significantly limits the scalability of ONoCs. For example, while using crossbar-based optical router, the minimum SNR in the 8×8 mesh-based ONoC is only 14dB, and its maximum BER is 10^{-3}. To achieve a BER of 10^{-9}, the maximum size of mesh-based ONoCs is 6×6 using the optimized crossbar-based optical router. We proposed a novel compact high-SNR optical router, called Crux, to improve the maximum size of mesh-based ONoCs to 8×8.

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2. CROSSTALK IN OPTICAL ROUTERS

Optical routers are the key components to build many types of ONoCs. They establish and maintain optical paths from sources to destinations for optical signals which carry payload data. The physical limitations imposed by integration necessitate a compact high-SNR optical router design while maintaining the level of functionality in ONoCs. A detailed analysis of optical routers paves the way for the network-level analysis in the next section.

2.1 Crosstalk in Optical Switching Elements

Optical routers are composed of microresonators and waveguides. In optical routers, waveguides and microresonators form two types of basic optical switching elements – parallel switching element and crossing switching elements (Figure 1). When two optical waveguides cross each other, they form a waveguide crossing (Figure 1a). In this paper, the radius of the microresonator based on silicon-on-insulator (SOI) technology is 5μm. The rectangular cross section of both ring and waveguide is 500nm wide and 250nm high. The basic optical switching elements can be powered on (the ON state) and off (the OFF state) by changing the voltage applied on the microresonators. The input optical signal with wavelength λ_S will propagate from the input port to the through port when the basic optical switching elements are in the OFF state (Figure 1b and d). When the basic optical switching elements are in the ON state, the optical signal will be coupled into the microresonators and then directed to the drop port (Figure 1c and e). Compared with the parallel switching element, the crossing switching element has a waveguide crossing which introduces non-negligible crossing insertion loss, L_C. The insertion loss per crossing is very small. When a large number of crossings are used in ONoCs, the total insertion loss is significant. When a waveguide bends, it also incurs the bending loss, L_B.

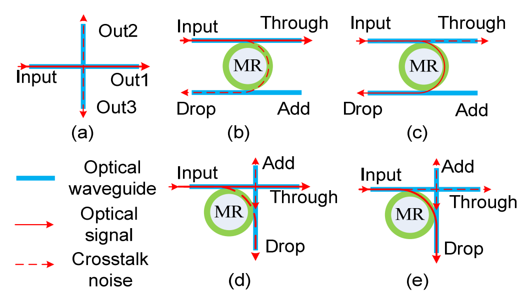


Figure 1. Basic optical switching elements (a) Waveguide crossing (b) Parallel switching element in OFF state (c) Parallel switching element in ON state (d) Crossing switching element in OFF state (e) Crossing switching element in ON state

Crosstalk is an intrinsic characteristic of microresonators and waveguide crossings. Crosstalk noise is caused by the undesirable coupling among optical signals when they pass microresonators and waveguide crossings. During crosstalk, a small portion of the power of one optical signal is directed to another optical signal and becomes noise. A waveguide crossing is an optical resonant cavity with four ports. Since the imperfect resonant cavity cannot prevent all the resonant modes that are excited from the input port from decaying into Out2 and Out3, there will be crosstalk on the undesired output ports. If P_I is the power of the input optical signal, the output powers at Out1, Out2 and Out3 ports are $P_{O1}=L_CP_I$ and

$P_{O2}=P_{O3}=K_1P_I$, where L_C is the power loss per crossing and K_1 is the crosstalk coefficient per crossing. P_{O2} and P_{O3} will become crosstalk noise when they are mixed with other optical signals.

The two basic optical switching elements also suffer from crosstalk. When an input optical signal goes through the basic optical switching elements, crosstalk noise will be generated in the other ports. When the parallel switching element is in the OFF state, the output powers at the through and drop ports can be calculated as $P_T=L_{P1}P_I$ and $P_D=K_2P_I$. While the parallel switching element is in the ON state, the output powers at the through and drop ports can be calculated as $P_T=K_3P_I$ and $P_D=L_{P2}P_I$. The output powers of the crossing switching element in the OFF state can be calculated as $P_T=L_{C1}P_I$, $P_D=(K_2+L^2_{P1}K_1)P_I$, and $P_A=K_1L_{P1}P_I$. When it is in the ON state, the output powers can be expressed as $P_D=L_{C2}P_I$, $P_T=L_CK_3P_I$, and $P_A=K_1K_3P_I$. P_T, P_D and P_A are the output powers of the through, drop and add ports, respectively. L_{P1} is the power loss, and K_2 is the crosstalk coefficient of the parallel switching element in the OFF state. L_{P2} and K_3 are the power loss and crosstalk coefficient when the parallel switching element is in the ON state. L_{C1} is the power loss of the crossing switching element in the OFF state. L_{C2} is the power loss of crossing switching element in the ON state. When the crossing switching element is powered on, its crosstalk model is the same as the parallel switching element. The values of the losses and crosstalk coefficients are shown in Table 1 and 2 [4][5].

Table 1. Optical power losses

L_C	L_{C1}	L_{C2}	L_B	L_{P1}	L_{P2}
-0.12dB	-0.125dB	-0.5dB	-0.005dB/90˚	-0.005dB	-0.5dB

Table 2. Crosstalk coefficients

K_1	K_2	K_3
-40dB	-45dB	-25dB

2.2 Optimized Crossbar and Crux Router

5×5 optical routers are required for mesh-based ONoCs. We optimized the crossbar-based optical router to minimize the insertion loss and crosstalk (Figure 2a). The optimized optical crossbar router uses dimension-order routing algorithm, which is a minimal path routing algorithm and is free of deadlock and livelock. The dimension-order routing algorithm is a low-complexity distributed routing algorithm and does not require any routing table. These make it particularly suitable for mesh-based ONoCs, which require both low latency and low cost. Since the turns from the Y to X dimensions and the U turns are not required, the number of microresonators can also be reduced to 16.

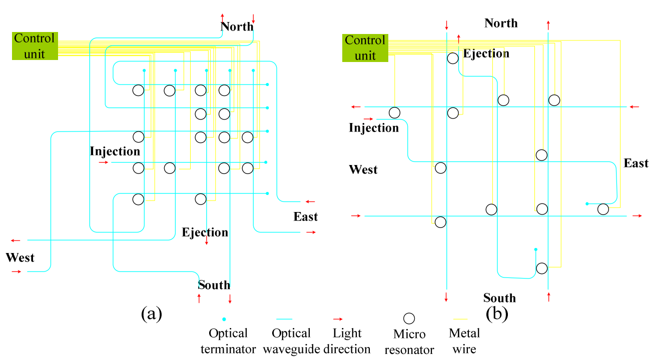


Figure 2. 5×5 optical routers (a) The optimized optical crossbar router (b) Crux router

Based on the two basic switching elements, we developed a new optical router, called Crux, to further minimize the insertion loss, crosstalk, and the number of microresonators (Figure 2b). Crux router only uses 12 microresonators to implement the strictly non-blocking 5×5 routing function required by the dimension-order routing algorithm. Both Crux and the optimized crossbar include a switching fabric and control unit. The routers have five bidirectional ports -- injection/ejection, east, south, west and north. The injection/ejection port is connected to a local processor core through an optical/electronic (O/E) interface. These five ports are aligned to their intended directions, and the input and output of each port are also properly aligned to ensure that no extra crossing or waveguide bending is required when multiple routers are connected to form mesh-based ONoCs.

Crux takes the advantages of the parallel switching element to minimize insertion loss and crosstalk. Different from the optimized crossbar, when optical signals travel in one dimension, Crux can passively route them and does not require to power on any microresonator. Only when optical signals use the injection/ejection port or make a turn from one dimension to the other, routers need to power on one microresonator. In Crux, the maximum number of waveguide crossings between the ports is five. These properties reduce not only the insertion loss but also the crosstalk noise caused by waveguide crossings. Moreover, regardless of the network size, the mesh-based ONoCs based on Crux only need to power on at most three microresonators to inject, turn and eject an optical signal between any pair of processor cores.

We developed an automated crosstalk analyzer for optical routers based on the analysis of the basic optical switching elements and waveguide crossings in the last section. The analyzer can explore the crosstalk noise, insertion loss, and SNR of arbitrary optical router architectures. We implemented it in C. An optical router architecture is described as a list of the basic switching elements, waveguide crossings, and their connections in an input file. A technology file includes all the parameters in Table 1 and 2. The analyzer helped us to optimize the crossbar-based optical router and design Crux.

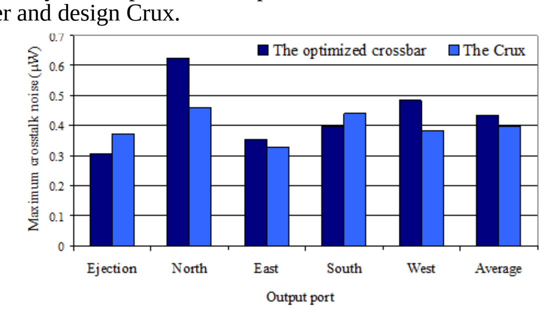


Figure 3. Maximum crosstalk noise at each port

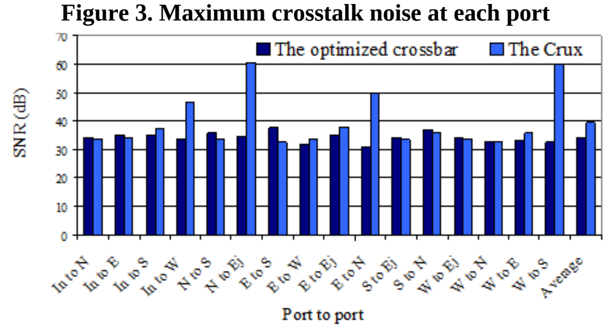


Figure 4. Minimum SNR of each signal path

Using the automated crosstalk analyzer, we analyzed the crosstalk noise and SNR for the optical routers. Figure 3 shows the maximum crosstalk noise at each output port when the optical power at each input port is 0dBm. The average maximum crosstalk noise in Crux is lower than in the optimized crossbar. Crux has lower crosstalk noise at the north, east, and west ports than the optimized crossbar. Although Crux has higher crosstalk noise at the ejection and south ports than the optimized crossbar, its SNR is better because optical signals encounter significantly less loss.

We analyzed the SNR of the optimized crossbar and Crux. Figure 4 shows the minimum SNR of each input port and output port combination. SNR is defined by equation (1), where P_s is the optical power of the signal and P_n is the power of the crosstalk noise. On average, the minimum SNR of Crux is 8dB higher than the optimized crossbar. The average minimum SNR of Crux is 40dB, while the average minimum SNR of the optimized crossbar is 32dB. The Crux has significantly better SNR for optical signals from north to ejection, injection to west, east to north, and west to south. In ONoCs, optical signals will encounter insertion loss at neighbor routers before reaching an optical router. Since Crux has low insertion loss, the ONoCs based on Crux will have higher signal power at each router input ports compared with the ONoCs based on the optimized crossbar. This will make Crux to have even higher SNR in ONoCs as we can see in the next section.

$$SNR = \frac{P_s}{P_n} \tag{1}$$

3. SNR AND BER OF MESH-BASED ONOCS

BER of an ONoC is directly influenced by its SNR. Since the more routers an optical signal passes, the more insertion loss it will suffer and the more crosstalk noise will be accumulated, the minimum SNR link between processor cores in an ONoC will cross a large number of optical routers. Although, the longest optical links, which traverse the largest number of optical routers in an ONoC, suffer the largest insertion loss, they may not be the minimum SNR link, because the crosstalk noise accumulated at each router on a link is also decided by the power levels of other input optical signals crossing the same router. This shows that the minimum SNR link in an ONoC should also be crossed by a large number of other high-power links.

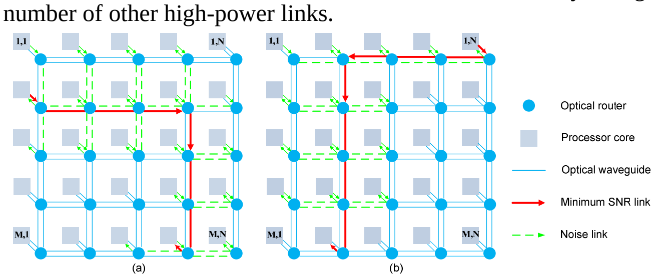


Figure 5. The minimum SNR links of mesh-based ONoCs using (a) optimized crossbar (b) Crux router

As an example, we systematically analyzed the SNR of mesh-based ONoCs. A mesh-based ONoC connects processor cores with M×N optical routers and uses the dimension-order routing algorithm. The following SNR and BER analysis is based on the router-level analysis in the last section. Our analysis finds one of the second or third longest links is the minimum SNR link in mesh-based ONoCs (Figure 5). Due to the different crosstalk and insertion loss properties of the optimized crossbar and Crux, the minimum SNR links of ONoCs based on them are the different second and third longest links. The minimum SNR link in the ONoC using the optimized crossbar is from processor core (2,1) to processor core (M,N-1). The minimum SNR link in the ONoC using Crux is from processor core (1,N) to processor core (M,2).

The two minimum SNR links are used as examples to illustrate our analysis process. On the minimum SNR link, the insertion loss of an optical router (i, j) at the X dimension, $L_{X,i,j}$, and at the Y dimension, $L_{Y,i,j}$, for ONoCs using the optimized crossbar and Crux can be expressed by Equation (2) to (5). In the equations, subscripts a and b denote the optimized crossbar and Crux respectively. On the right sides of the equations, the second subscripts denote the router input ports, and the third subscripts denote the router output ports. Based on Equation (2) to (5), the insertion loss suffered by the minimum SNR link can be expressed by Equation (6) and (7). In the equations, the five terms on the right side represent respectively the insertion losses from the source processor to the first optical router, on the X dimension section of the link, at the optical router where the link turns from the X to Y dimension, on the Y dimension section of the link, and at the optical router connected to the destination processor.

$$L_{a,X,i,j} = \begin{cases} L_{a,In,E} & i=2, j=1 \\ L_{a,W,E} & i=2, 2 \le j \le N-2 \end{cases} \tag{2}$$

$$L_{b,X,i,j} = \begin{cases} L_{b,In,W} & i=1, j=N \\ L_{b,E,W} & i=1, 3 \le j \le N-1 \end{cases} \tag{3}$$

$$L_{a,Y,i,j} = \begin{cases} L_{a,W,S} & i=2, j=N-1 \\ L_{a,N,S} & 3 \le i \le M-1, j=N-1 \\ L_{a,N,Ej} & i=M, j=N-1 \end{cases} \tag{4}$$

$$L_{b,Y,i,j} = \begin{cases} L_{b,E,S} & i=1, j=2 \\ L_{b,N,S} & 2 \le i \le M-1, j=2 \\ L_{b,N,Ej} & i=M, j=2 \end{cases} \tag{5}$$

$$L_{a,SNR_{\min}} = L_{a,In,E} + (N-3)L_{a,W,E} + L_{a,W,S} + (M-3)L_{a,N,S} + L_{a,S,Ej} \tag{6}$$

$$L_{b,SNR\min} = L_{b,In,W} + (N-3)L_{b,E,W} + L_{b,E,S} + (M-2)L_{b,N,S} + L_{b,N,Ej} \tag{7}$$

Crosstalk noise will be introduced by both the optical signal on the minimum SNR link and the optical signals on other links crossing the minimum SNR link through optical routers. The power of the crosstalk noise introduced at the optical router j on the X dimension section of the minimum SNR link, N_X, is shown in Equation (8) and (9). The introduced noise power at the optical router i on the Y dimension section of the link, N_Y, is shown in Equation (10) and (11). In the equations, P_{in} is the optical input power at the injection port. The total crosstalk noise can be calculated by summing the crosstalk noise from each router on the link, while the total insertion loss of the link is given by Equation (6) and (7).

$$N_{a,X,j} = \begin{cases} L_{a,In,S} P_{in} \frac{L_{a,N,S}}{L_{C1}} L_{C2} L_B (k_1 + L_C^2 k_2) + L_{a,In,W} L_{a,E,Ej} P_{in} L_{C2} L_B k_1 & j=1 \\ L_{a,In,W} \frac{L_{a,W,E}}{L_C^2 L_B} P_{in} k_1 + L_{a,In,W} L_{a,E,Ej} P_{in} L_{C2} L_B (k_1 + L_C^2 k_2) & \\ + L_{a,In,N} L_{a,S,N} \frac{L_{a,W,E}}{L_C^3 L_B^4} P_{in} k_1 + L_{a,In,S} \frac{L_{a,N,S}}{L_{C1}} P_{in} L_{C2} L_B (k_1 + L_C^2 k_2) & 2 \le j \le N-2 \end{cases} \tag{8}$$

$$N_{b,X,j} = \begin{cases} 0 & j=N \\ \frac{L_{b,In,E}}{L_B^4 L_C L_{C1}^2 L_{p2}} P_{in} k_2 + L_{b,In,E} \frac{L_{b,W,Ej}}{L_B^2} P_{in} (k_2 + L_{p1}^2 k_1) & 3 \le j \le N-1 \end{cases} \tag{9}$$

$$N_{a,Y,i} = \begin{cases} L_{a,In,W} \frac{L_{a,W,S}}{L_C^2 L_B} P_{in} k_1 + L_{a,In,S} \frac{L_{a,N,Ej}}{L_{C1}} P_{in} L_{C2} (k_1 + L_C^2 k_2) & \\ + L_{a,In,W} L_{a,E,N} \frac{L_{a,W,S}}{L_C^3 L_B^4} P_{in} k_1 + L_{a,In,W} \frac{L_{a,E,N}}{L_{C1} L_B^4} P_{in} L_{C2} (k_1 + L_C^2 k_2) & i=2 \\ L_{a,In,W} \frac{L_{a,E,Ej}}{L_{C1}} P_{in} L_{C2} (k_1 + L_C^2 k_2) + \frac{L_{a,In,E}}{L_{C1} L_B L_{C2}} P_{in} (k_2 + L_{p1}^2 k1) & 3 \le i \le M-1 \\ L_{a,In,W} \frac{L_{a,E,W}}{L_C^4 L_B} P_{in} L_{C2} L_{C1} k_1 + P_{in} L_{C1}^3 k_1 & i=M \end{cases} \tag{10}$$

$$N_{b,Y,i} = \begin{cases} \frac{L_{b,In,E}}{L_B^2 L_C L_{C1} L_{p2}} P_{in} (k_2 + L_{P1}^2 k_1) + L_{b,In,E} P_{in} (k_2 + L_{P1}^2 k_1) & \\ + L_{b,In,E} \frac{L_{b,W,Ej}}{L_B^2 L_{P1}} P_{in} L_{C1} L_{C2} (k_1 + L_C^2 k_2) & i=1 \\ \frac{L_{b,In,E}}{L_B^2 L_C L_{C1} L_{p2}} P_{in} (k_2 + L_{P1}^2 k_1) + L_{b,In,W} \frac{L_{b,E,W}}{L_{p1}} P_{in} L_{C1} (k_2 + L_{P1}^2 k_1) & \\ + L_{b,In,E} P_{in} (k_2 + L_{P1}^2 k_1) + L_{b,In,E} \frac{L_{b,W,Ej}}{L_{p1}} P_{in} L_{C1}^3 k_2 & 2 \le i \le M-1 \\ 0 & i=M \end{cases} \tag{11}$$

Based on Equation (1) and (6) to (11), the minimum SNR of mesh-based ONoCs with M×N optical routers can be shown (Equation (12) and (13)). Equation (12) is derived from Equation (1), (6), (8) and (10) and shows the minimum SNR of the ONoCs using the optimized crossbars. Equation (13) is based on (1), (7), (9) and (11) and shows the minimum SNR of the ONoCs using Crux routers.

$$SNR_{a,\min,M,N} = \frac{L_{a,In,E} L_{a,W,E}^{N-3} L_{a,W,S} L_{a,N,S}^{M-3} L_{a,N,Ej}}{N_{a,X,1} L_{a,W,E}^{N-3} L_{a,W,S} L_{a,N,S}^{M-3} L_{a,N,Ej} + L_{a,W,S} L_{a,N,S}^{M-3} L_{a,N,Ej} \left(\frac{1-L_{a,W,E}^{N-3}}{1-L_{a,W,E}} N_{a,X,2} \right) + L_{a,N,Ej} L_{a,N,S}^{M-3} N_{a,Y,2} + L_{a,N,Ej} \left(\frac{1-L_{a,N,S}^{M-3}}{1-L_{a,N,S}} N_{a,Y,3} \right) + N_{a,Y,M}} \quad (12)$$

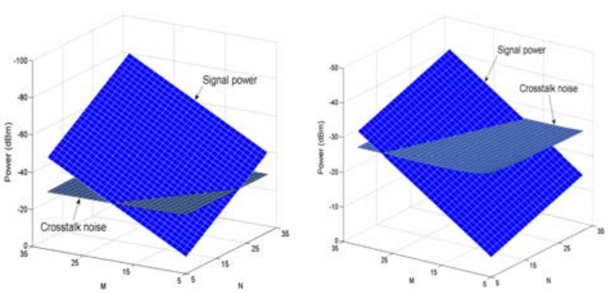
$$SNR_{b,\min,M,N} = \frac{L_{b,In,W} L_{b,E,W}^{N-3} L_{b,E,S} L_{b,N,S}^{M-2} L_{b,N,Ej}}{L_{b,E,S} L_{b,N,S}^{M-2} L_{b,N,Ej} \left(\frac{1-L_{b,E,W}^{N-3}}{1-L_{b,E,W}} N_{b,X,3} \right) + N_{b,Y,1} L_{b,N,Ej} L_{b,N,S}^{M-2} + L_{b,N,Ej} \left(\frac{1-L_{b,N,S}^{M-2}}{1-L_{b,N,S}} N_{b,Y,2} \right)} \quad (13)$$

BER is the percentage of bits that have errors among the total number of bits received during a transmission. ONoC with a high BER will require error correction coding and even retransmissions if errors can be found but not corrected. For optical signals using non-return-to-zero (NRZ) line code, ONoCs can be modeled as on-off keying (OOK) systems. The BER and the SNR relation of the OOK system is defined in equation (14) [6]. Based on Equation (12) to (14), the maximum BER of mesh-based ONoCs can be calculated.

$$BER = \frac{1}{2} e^{-\frac{SNR}{4}} \quad (14)$$

4. SIMULATIONS AND ANALYSIS

We studied the relationship between the network size and the crosstalk noise, SNR, and BER of the mesh-based ONoCs using the optimized crossbar and Crux. Numerical simulations are performed using MATLAB. Figure 6a shows the power of optical signal and crosstalk noise at the destination on the minimum SNR link of the ONoCs using the optimized crossbar. We find that as the network size increases, the optical signal power received by the destination processor core drops quickly, and the crosstalk noise power increases relatively slow. This is due to the large insertion loss of the optimized crossbar, which not only attenuates optical signals but also the crosstalk noise. When the ONoC size is larger than 14×14, the optical signal power is smaller than the crosstalk noise power. For instance, when the ONoC size is 16×16 and P_{in} is 0dBm, the signal power is -39.3dBm and the crosstalk noise power is -31.4dBm.



(a) Optimized crossbar **(b) Crux router**

Figure 6. Signal and crosstalk noise power in the M×N ONoCs

Figure 6b shows the optical signal power and crosstalk noise power reached the destination processor core on the minimum SNR link of the ONoCs using Crux routers. It shows that as the ONoC size increases, the optical signal power decreases and the crosstalk noise power slowly increases. Compared with the ONoCs using the optimized crossbar, the optical signal power decreases much slower in the ONoCs using Crux router. For example, when the ONoC size is 16×16, the optical signal power is -20.9dBm and the crosstalk noise power is -28.2dBm. The optical signal power in the ONoC using Crux is 18.4dB higher than in the ONoC using the optimized crossbar. This is due to the smaller insertion loss in Crux than in the optimized crossbar. Although Crux causes less crosstalk noise, its small insertion loss gives less attenuation to the crosstalk noise from neighboring routers.

The minimum SNR in the MxN ONoCs using the optimized crossbar and Crux is shown Figure 7. It shows that as the ONoC size increases, minimum SNR will decrease. However, the minimum SNR in the ONoCs using Crux routers decreases significantly slower than in the ONoCs using the optimized crossbar. The minimum SNR in the ONoCs using Crux is always higher than in the ONoCs using the optimized crossbar, and the difference is significantly larger than those shown in Figure 4, which compares the SNRs of stand-alone routers. For example, when the size of the ONoCs using the optimized crossbar is 8×8, the minimum SNR is 14dB and when the size is 16×16, the minimum SNR will decrease to -7.9dB, which indicates that the crosstalk noise power is higher than the optical signal power.

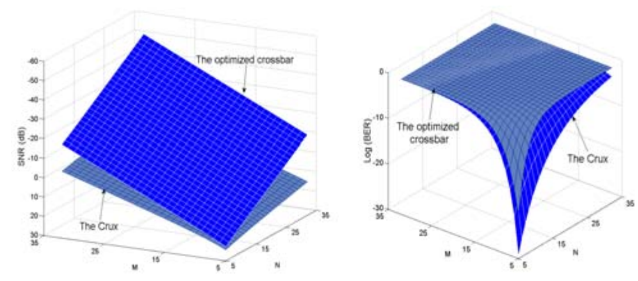


Figure 7. Minimum SNR and maximum BER in M×N ONoCs

Figure 7b shows the maximum BER of MxN ONoCs using the optimized crossbar and Crux routers. BER increases exponentially as SNR decreases. As the ONoC size increases, the maximum BER also increases. For example, when the size of ONoCs using the optimized crossbar is 8×8, the maximum BER is 10^{-3}, and the number increases alarmingly to $10^{-0.3}$ when the size is 16×16. To achieve the BER of 10^{-9} for reliable transmissions, the ONoCs using the optimized crossbar should not be larger than 6×6. The maximum BER in the ONoCs using Crux is always lower than in the ONoCs using the optimized crossbar. To achieve the BER of 10^{-9}, the size of ONoCs using Crux can increase to 8×8, which is considerably larger than the maximum size of the ONoCs using the optimized crossbar.

5. CONCLUSION

Crosstalk noise is an intrinsic characteristic of photonic devices used by ONoCs. Although it is very small at device level, our analysis shows that crosstalk has a significant impact on the BER of ONoCs at system level. The minimum SNR and maximum BER are the limiting factors of ONoC design. For the first time, we present the analytical models of the minimum SNR and maximum BER in mesh-based ONoCs. We showed that a properly designed optical router, such as Crux, could significantly improve the SNR and scalability of ONoCs.

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