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Crosstalk noise aware wavelength allocation in WDM 3D ONoC

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Abstract

Optical Network-on-Chip (ONoC) employs Wavelength Division Multiplexing (WDM) supporting multiple transactions at same time. In this context, many senders and receivers can share the same waveguide to increase the total bandwidth utilization. However, simultaneous transmissions on closed adjacent wavelengths may introduce crosstalk noise through different optical switching elements within the network due to the low wavelength channel spacing and the large Full Width at Half Maximum (FWHM) of the resonance pic of the Microring Resonator (MR). To address this problem, this paper proposes crosstalk noise aware wavelength allocation in WDM 3D ONoC to improve Signal to Noise Ratio (SNR) performance.

1. Introduction

Given the evolution of MPSoC, we currently focus on chips with hundreds of IP cores. To cope with huge communication requirement, Network-on-chip (NoC) design has been put forward to replace bus-based design. However, the limitation of electrical interconnects, such as capacitive and inductive coupling [5], interconnect noise and increased propagation delay of global interconnect, has severely hindered the further improvement of NoC. A 3D architecture based on an optical interconnection for an MPSoC is one of the key solutions to solve the above limitations. It relies on optical waveguides carrying optical signals and provides low latency, high bandwidth properties and high noise immunity to the communication medium. The waveguide for data transmission can be shared by multiple senders and receivers. Moreover, Wavelength Division Multiplexing (WDM) [2] is employed to support multiple transactions at same time.A communication between a source and a destination can be established by using several wevelenghts in parallel in order to reduce the communication time. However, simultaneous transmissions, on closed adjacent wavelengths, may introduce crosstalk noise through different optical switching elements within the network which degrades system performance [1]. Indeed, Micro Resonators (MR) are used to inject or drop optical signal to the waveguide to send or receive data. They act like non-ideal filters and drop an amount of power of the optical signals proportional to the distance between the optical signal wavelenght and the resonance wavelength of the MRs. This paper addresses this problem and propose to reduce the crosstalk by an efficient wavelength allocation. Many of the previous research works are focused on developing models at the device level for the worst-case crosstalk noise and SNR in different ONoCs [4] [1]. They demonstrate that the crosstalk noise is a critical concern in large-scale WDM 3D ONoC. To the best of our knowledge, none of previous works have explored wavelength spacing for overlapped communication to minimize crosstalk noise.

2 Crosstalk noise problem

As shown in the example presented in the Fig. 1(a), 3 Optical Network interfaces (ONIs) are crossed by a waveguide with 3 wavelengths. We note $\lambda_{C_{i,j}}$ the reserved wavelength for a communication between ONI_i and ONI_j. The crosstalk noise appears because two low spacing wavelengths $\lambda_{C_{i,j}}$ and $\lambda_{C_{m,n}}$ reach simultaneously a on-state MR. Fig. 1(b) shows that the crosstalk noise is higher with the smaller channel spacing between $\lambda_{C_{i,j}}$ and $\lambda_{C_{m,n}}$. In ONI_3, a part of light from $\lambda_{C_{1,3}}$ is also filtered by on-state MR specific to λ_1, introducing crosstalk noise on optical signal on λ_1 (red color). In data transmission, the crosstalk noise decreases SNR which increases the BER of the optical signal. Considering the introduction of crosstalk noise is inevitable, it is importance to reduce the affection on SNR. In this example, we have 2 choices (λ_2 and λ_3) for communication between ONI_1 and ONI_3. Figures 1(c) and 1(d) show the crosstalk noise introduced by λ_2 and λ_3 on MR_{λ_1} of ONI_3 respectively. The filtered power of λ_3 is smaller compared to that of λ_2. Hence we choose λ_3 for $C_{1,3}$ which leads to a better SNR. Wavelength allocation is hence vital to reduce crosstalk noise in the network. Our idea is to space out two overlapped wavelengths as far as possible to maximize SNR in order to be able top reduce the power of laser if a specific BER is targeted.

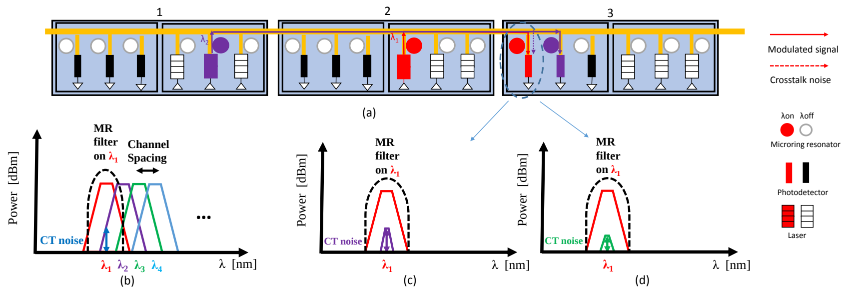

Figure 1: (a) Communication example ; (b) Crosstalk noise illustration ; Crosstalk noise : (c) if $\lambda_{C_{1,3}} = \lambda_2$; (d) if $\lambda_{C_{1,3}} = \lambda_3$

3 Power model

Definition 1: The overlapped communications graph (OCG) for an application is a directed graph, $\mathcal{GC} = \{\mathcal{C}, \mathcal{E}\}$ with each vertex $C_{i,j}^m \in \mathcal{C}$ represents the communication between ONI_i and ONI_j on one wavelength $\lambda_{C_{i,j}^m}$, and each edge defines the overlapped relationship between $\lambda_{C_{k,l}^n}$ and $\lambda_{C_{i,j}^m}$. The edge between $C_{i,j}^m$ and $C_{k,l}^n$ exists if temporal and spatial conflict for these two communications appear simultaneously. The edge direction means the source signal of crosstalk noise to the detected signal. The weight of edge $E_{C_{i,j}^m, C_{k,l}^n} \in \mathcal{E}$ can be expressed as below:

$$E_{C_{i,j}^m, C_{k,l}^n} = \frac{P^j_{\lambda_{C_{k,l}^n}}}{P^j_{\lambda_{C_{i,j}^m}}} \quad \forall m,\ n;\ \lambda_{C_{k,l}^n} \neq \lambda_{C_{i,j}^m} \tag{1}$$

Where $P^j_{\lambda_{C_{k,l}^n}}$ represents the power of signal carried on $\lambda_{C_{k,l}^n}$ arriving at ONI_j, $P^j_{\lambda_{C_{i,j}^m}}$ represents the power of signal carried on $\lambda_{C_{i,j}^m}$ arriving at ONI_j. In this case, $C_{i,j}^m$ arrives at its destination ONI_j and the MR specific to $\lambda_{C_{i,j}^m}$ is turned on. A portion of the signal carried on $\lambda_{C_{k,l}^n}$ is also filtered by the ON-state MR introducing crosstalk noise on detected signal. Hence, $E_{C_{i,j}^m, C_{k,l}^n}$ indicates the degree of crosstalk noise of $\lambda_{C_{k,l}^n}$ added on $\lambda_{C_{i,j}^m}$. We propose a heuristic algorithm to allocate wavelengths of $Edge_{sort} = SortUpDown_{by\ edges\ values}(Edge)$. Our idea is, like greedy algorithm, to follow the priority of weights of edges and make the locally optimal choice at each step, then find a global suboptimal solution. We derived the signal power at the photodetector in equation (2).

$$P^j_{\lambda_{C_{i,j}^m}} = P_{Laser} + L_{MR-off} + L_{MR-on} + L_P + L_B \tag{2}$$

L_P and L_B are the propagation and bending losses along the ONI_i and ONI_j. L_{MR-off} and L_{MR-on} are the loss introduced by OFF-state and ON-state MR along the ONI_i and ONI_j.

4 Simulation results

To prove that the choice of wavelengths heavily affects the SNR performance, we consider the following experiments. Figure 2 illustrates the mapping of the tasks on

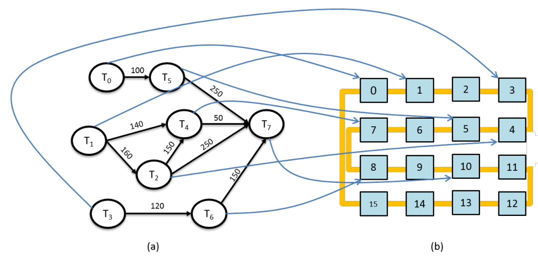

Figure 2: Mapping of the tasks on the different IPs

different IPs. The right-hand side of Figure 2 represents 8 ONIs crossed by one waveguide propagating optical signals. The arrows represent the mapping of 8 tasks onto the IP connected to the ONIs. For example, T_0 is assigned to IP_0. We assume that 4 wavelengths are integrated in the waveguide and each communication can reserve one wavelength. The wavelength allocation results by the proposed heuristic algorithm based on OCG are resumed in table 1. For example, λ_1 is allocated to $C_{0,5}$. The related $\overline{SNR}$ is equal to 9.58 dB, compared to 3.85 dB for the naive method [3].

Table 1: Wavelengths allocation results

$C_{0,5}$	$C_{5,10}$	$C_{1,7}$	$C_{7,10}$	$C_{3,8}$	$C_{8,10}$	$C_{1,4}$	$C_{4,7}$	$C_{4,10}$
λ_1	λ_3	λ_3	λ_1	λ_2	λ_4	λ_4	λ_4	λ_1

5. Conclusion

Crosstalk noise heavily affects the SNR performance in Optical network-on-chip. In this paper, we introduce a crosstalk noise aware wavelength allocation model which allows to improve SNR performance.

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