Work-in-Progress: Mitigating Inter-Channel Crosstalk Non-Uniformity in Microring Filter Arrays of Photonic NoCs

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ABSTRACT

Photonic networks-on-chip (PNoCs) employ photonic links with dense-wavelength-division-multiplexing (DWDM) of channels for parallel signal traversal, along with arrayed microring resonator (MR) filters for parallel signal reception, to enable high-bandwidth on-chip data transfers. Unfortunately, DWDM induces non-uniform inter-channel crosstalk in an MR filter array, which degrades the communication reliability in the link. Overcoming this reliability degradation requires non-uniformly distributed signal power across the utilized data-channels in the link. This increases the total laser power consumption of the link, compared to the ideal case where the crosstalk distribution in the MR filter array is uniform. This paper presents a novel design of MR filter array with minimized crosstalk non-uniformity, which can achieve total optical laser power savings of up to 34% of the link power budget.

KEYWORDS: Non-Uniform Quality Factor, Crosstalk, Photonic NoCs, Microring Filters.

1 INTRODUCTION AND MOTIVATION

To overcome the performance bottlenecks of on-chip communication with ENoCs, recent advances in CMOS-photonics integration [1] have enabled an exciting solution in the form of photonic NoCs (PNoCs). Several PNoC architectures have been proposed to date (e.g., [2]–[4]). These architectures employ on-chip photonic links, each of which connects two or more clusters of processing cores. Each photonic link comprises one or more photonic waveguides with dense wavelength division multiplexing (DWDM) of multiple wavelength channels into each waveguide. In a DWDM-enabled waveguide, microring resonator (MR) modulators, which are typically arrayed along the waveguide at the source end, modulate input electrical data signals onto parallel photonic channels. The resultant photonic signals travel through the waveguide and reach the destination end, where, an array of MR filters drop the parallel photonic signals onto the adjacent photodetectors to recover the electrical data signals. Thus, DWDM enables high bandwidth parallel data transfers in PNoCs.

Unfortunately, DWDM links of PNoCs may suffer from spectral degradation of photonic channels and inter-channel crosstalk [5], which is treated as an optical power penalty in our model. The power penalty is the extra optical power required to compensate for the effects of signal degradation on bit-error-ratio (BER) [6]. As discussed in [6], due to the non-ideal transmission characteristics of DWDM photonic links and MR filter arrays, the photonic channels at the receiver end of a photonic link face non-uniform magnitudes of crosstalk and related power penalties. For example, Fig. 1 illustrates the MR filter array of an example single-waveguide DWDM link with 16 photonic channels (λ_1-λ_{16}). From the figure, every MR filter in the array drops varying amount of power from the neighboring channels on its drop port as crosstalk. The first and last MR filters (λ_1 and λ_{16}) have crosstalk channels on only one side of the DWDM spectrum. Therefore, they see the least crosstalk power at their drop ports. Moreover, as the photonic signals travel along the waveguide, they are progressively dropped by the MR filters, contributing progressively varying amount of crosstalk at the drop ports of MR filters. As a result, the MR filter array sees a non-uniform distribution of crosstalk power penalties across the photonic channels (Fig. 2, Baseline – red curve). For example, from Fig. 2 (red curve), MR #16 (λ_{16}) faces the minimum crosstalk penalty of 2.1dB, whereas MR #7 (λ_7) faces the maximum crosstalk penalty of 6.3dB, yielding the variance in penalty across the array to be 4.2dB.

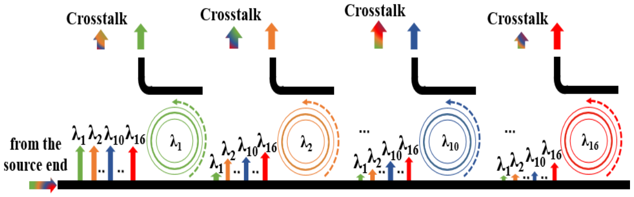

Fig. 1: An array of MR filters at the receiver end of a silicon photonic DWDM link. The heights of the crosstalk arrows are proportional to the corresponding power penalty values.

Overcoming these non-uniformly distributed crosstalk penalties, which is imperative to achieve uniform BER across all the channels, requires non-uniformly distributed laser power across the channels (Baseline results in Fig. 3 – red bars). This in turn results in total 34.36mW of laser power overprovisioning (patterned red bars in Fig. 3) for all channels in the link, compared to the ideal case (solid red bars in Fig. 3) where the distribution of crosstalk penalty and laser power across all the channels is uniform. *Therefore, to minimize the total laser power overprovisioning in the link, the crosstalk penalty distribution in the MR filter array should be uniformized.*

As examined in [6], reshuffling the assignments of the individual MR filters to the utilized photonic channels (so that MR #1 is not assigned to λ_1 channel, and so forth) can flatten the crosstalk penalty distribution and reduce the total laser power overprovisioning in the link. The blue curve in Fig. 2 shows

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crosstalk penalty distribution across the MR filter array for the best pattern out of all possible reshuffled filter-channel assignments. This pattern yields minimum crosstalk penalty of 2.2dB for MR #12 (channel λ_{16}) and maximum crosstalk penalty of 6.3dB for MR #2 (channel λ_{10}), resulting in total laser power overprovisioning of 32.3mW for the link (Fig. 3 – blue bars) that is 4mW less than the baseline case. *This improvement in crosstalk penalty distribution and resultant reduction in the total laser power overprovisioning is negligible*. As a result, the non-uniformity in the crosstalk penalty distribution across the MR filter array still exists. *To overcome this problem, we propose a novel design of MR filter array with a non-uniform quality-factor distribution across the individual MR filters*, as discussed next.

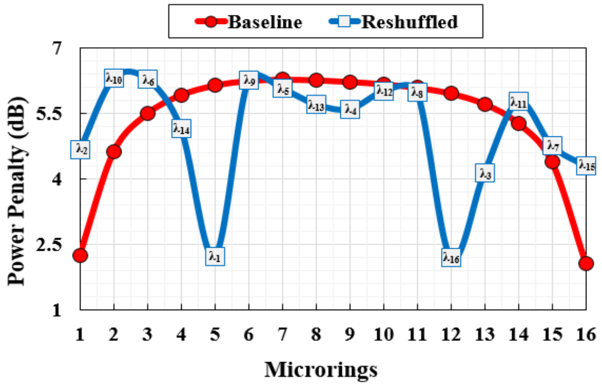

Fig. 2: Crosstalk penalty distribution across the MR filter array for two different cases. The values are obtained for 50GHz spacing and MR quality-factor of 8000, using the models from [6].

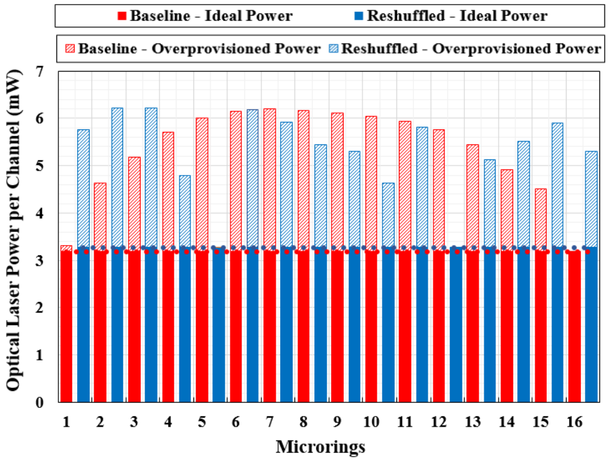

Fig. 3: Optical laser power per channel, for the baseline and reshuffled cases, evaluated for 50GHz spacing, MR quality-factor of 8000, and total link power budget of 100mW.

2 PROPOSED METHOD

In our proposed method, to achieve a uniform distribution of crosstalk penalty across the channels, each individual MR filter in the array is designed with a different quality-factor (Fig. 4(a); yellow curve – right vertical axis). As a result, our designed MR filter array achieves a flat/uniform distribution of power penalty across the channels, as shown in Fig. 4(a) (green curve – left vertical axis). With the uniformized crosstalk penalty distribution across the channels, the total laser power overprovisioning reduces to 76 µW, which in turn reduces the total link power to 51 mW (Fig. 4(b) – green bar). *Compared to the reshuffled design of MR filter array from [6], the total laser power overprovisioning in the link for our design reduces by 32 mW. Moreover, the total link power for our design also reduces by 34 mW, which is 34% of the total link power budget of 100mW*. This is because a higher quality-factor for an MR filter in our designed array reduces the crosstalk power at its drop port, as the crosstalk power is inversely related to the MR quality-factor [6]. Therefore, carefully choosing the quality-factor of each MR filter in our designed array based on an exhaustive search plays a vital role in uniformizing the crosstalk penalty across the channels.

We propose to define the quality-factor of each MR filter in our filter array at the design time. For that we adopt the MR design from [7], where every MR has an embedded PN-junction at its drop-port. From [7], the carrier concentration in the drop-port PN-junction can be dynamically altered to modulate the drop-port coupling coefficient, and consequently, the loaded quality factor of an MR.

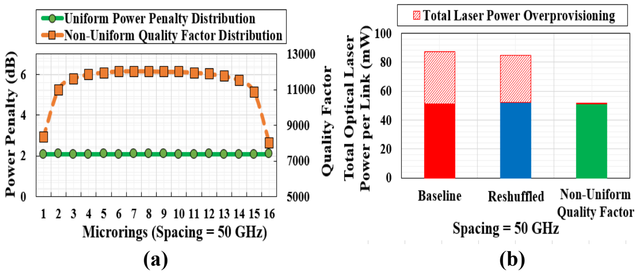

Fig. 4: (a) Uniform distribution of crosstalk penalty and non-uniform distribution of quality-factors, across the MR filters, and (b) total link-level optical laser power for three different cases. Our analysis utilizes models from [6] with link power budget of 100mW.

3 CONCLUSIONS AND FUTURE WORK

This paper presents a novel idea of using a non-uniform quality-factor distribution across an array of MR filters in a photonic link, to uniformize their crosstalk performance, and hence, decrease the total laser power consumption in the link. Our analysis shows that DWDM photonic links that utilize our designed MR filter array can achieve total optical laser power savings of up to 34 mW. In the future, we plan to perform a detailed analysis for photonic networks-on-chip, with different channel gaps and bit-rates, to evaluate the power and energy impacts of our designed MR filter arrays at the system-level.

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