Towards Energy-Proportional Optical Interconnects

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***Abstract*—Photonic interconnects have emerged as the prime candidate technology for efficient networks on chip (NoCs). However, the high optical loss of nanophotonic components coupled with the low efficiency of laser sources result in exceedingly high laser power requirements. As optical interconnects stay on even during periods of system inactivity, most of this power is wasted. In this paper we propose ProLaser, a laser control mechanism that has been co-designed with the cache coherence protocol to turn the lasers off when not needed and turn them back on just-in-time when communication is imminent. Overall, ProLaser saves 49-88% of the laser power and closely tracks (within 2-6%) a perfect prediction scheme with full knowledge of future interconnect requests. Moreover, the power savings of ProLaser allow the cores to exploit a higher power budget and run faster, achieving speedups of 1.5-1.7x and 35-52% lower energy consumption.**

I. Extended Summary

Lasers consume a significant amount of power in silicon-photonic interconnects because their output power needs to be high enough to compensate for the optical loss of silicon waveguides, optical couplers, and on-ring resonators. For example, silicon waveguides with optical loss of 0.1-0.3 *dB/cm* forming serpentine waveguides (16 *cm* for a 580 mm^2 Firefly chip [5]) increase the laser power by 1.5-3x. Process variations force designers to increase the laser power even higher to maintain a safety margin. To make matters worse, WDM-compatible lasers are highly inefficient, with efficiencies in the range of 5-10% [7] for on-chip lasers and 30% [3] for off-chip gaussian comb lasers. Thus, the required wall-plug laser power can easily grow by 10-20x when all the losses and inefficiencies are factored in. Unfortunately, the majority of this power is wasted as interconnects often stay idle for long periods of time during compute-intensive execution phases or in the cloud (servers in Google-scale datacenters are 30% utilized [1]).

In this paper we propose *Proactive Laser* (***ProLaser***), a laser control mechanism that turns the lasers of a photonic NoC off when not needed, and turns them on just-in-time when communication is imminent. ProLaser is co-designed with the cache coherence protocol, and (a) monitors the messages sent in a photonic NoC and correlates them to cache coherence events to predict future messages and turn on the laser proactively, (b) segregates data from control and turns on the data lines only when it predicts messages that carry data, and (c) employs a Bloom filter [6] in front of the L2 cache slice of each node in the NoC to predict cache misses, and turn on the laser sufficiently early to hide the entire laser turn-on delay. To maximize its impact, ProLaser utilizes fast lasers with a turn-on delay of a few *ns* [2, 4] to implement both on-chip and off-chip laser sources. More specifically, our contributions are:

1. We quantify the benefits of controlling on-chip and off-chip laser sources over a wide range of turn-on delays.
2. We design ProLaser, a near-optimal adaptive laser gating mechanism that turns on the lasers only when necessary.
3. We evaluate the impact of ProLaser on the performance and energy of a multicore. ProLaser saves 49-88% of the laser power, outperforms the state of the art by 2x, and tracks within 2-6% a perfect laser gating scheme.
4. We show that the power savings of ProLaser allow for providing a higher power budget to the cores, which enables them to run faster and achieve 50-70% speedup (60% on average) and 35-52% lower energy consumption (40% on average) on R-SWMR crossbars [5].

This work is partially supported by NSF CAREER award CCF-1453853.

II. Speaker Bio

Nikos Hardavellas is an Assistant Professor of Electrical Engineering and Computer Science at Northwestern University, where he co-founded and co-directs the Intel Parallel Computing Center (IPCC). His research interests are at the intersection of computer architecture and optical interconnects, memory systems, approximate computing, and design for dark silicon. Nikos received the June and Donald Brewer Chair at Northwestern University in 2009, became a Fellow of the Searle Center for Teaching Excellence in 2012, was a keynote speaker at IEEE ISPDC in 2010, and received an NSF CAREER award in 2015, an IEEE Micro Top Picks Award in 2009, a Best Demonstration Award in ICDE 2006, and a Technical Award for Contributions to the Alpha Microprocessor in 2000. Prior to joining Northwestern University, he contributed to the design of several generations of Alpha processors and high-end multiprocessor servers at Digital Equipment Corp. (DEC), Compaq, and Hewlett-Packard. Nikos holds a Ph.D. in Computer Science from Carnegie Mellon University.

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