Multiband Photonic Integrated WSS beyond 1Tb/s Data Center Interconnect Technology

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***Abstract*—This paper presents a novel approach for enhancing Data Center Interconnect (DCI) systems by proposing a modular multi-band Wavelength Selective Switch (WSS) based on Photonic Integrated Circuits (PICs). The proposed architecture enables the WSS to operate over a wide spectrum, supporting more output fibers and channels while occupying a smaller footprint. In a random metro network scenario, network performance evaluations demonstrate improved traffic distribution and channel allocation for 800G and 1200G transmission systems. These findings provide valuable insights for optimizing network configurations and enhancing overall performance in DCI applications.**

***Index Terms*—Data Center Interconnect, Photonic Integrated Circuits, Multi-band Transmission, Wavelength Selective Switch**

I. Introduction

According to current projections, there is an expected 30% Compound Annual Growth Rate (CAGR) for global Internet traffic [1]. This exponential increase in bandwidth demand necessitates the scaling up of Data Center Interconnect (DCI) to accommodate higher rates. To address this growing demand, deploying 400 ZR significantly enhances 400 G operations through dual-polarization coherent detection technology. The successful adoption of coherent optical communication technologies in commercial implementations showcases their potential as a viable solution for 400 G DCI and beyond [2]. In the context of 800 G and 1200 G systems, the emphasis is on utilizing higher baud rates and conventional modulation formats.

The deployment of Spatial Division Multiplexing (SDM) solutions necessitates a comprehensive overhaul of the optical transport infrastructure involving the integration of new fibers and devices. In contrast, the utilization of Bandwidth Division Multiplexing (BDM) offers a practical solution to increase the capacity of the optical network without the need for additional optical fibers. While optical amplification poses a significant challenge for BDM systems, several prototype amplifiers now operate in the extended-spectrum region. For BDM to enable transparent wavelength routing, it requires filtration and switching elements such as Wavelength Selective Switches (WSS). These components allow for autonomous management and routing of input channels to the Wavelength Division Multiplexing (WDM) comb fiber output. Traditional WSS devices typically rely on bulky and complex technologies like Liquid Crystal on Silicon (LCoS) and Microelectromechanical Systems.(MEMS) [3].

This research article proposes a novel approach utilizing Photonic Integrated Circuits (PICs) technology for developing a modular multi-band WSS [4]. Unlike conventional WSS systems that rely on MEMS and LCoS technologies, which tend to be bulky, the suggested modular architecture leverages PICs for improved performance. This approach enables the WSS to operate over a broad portion of the optical spectrum, including the L+C+S bands. Moreover, it can support more output fibers and channels while occupying a smaller physical footprint than MEMS-based alternatives. It is important to note that the proposed architecture focuses solely on the switching functionality of the WSS module and does not consider the local add/drop module of the Reconfigurable Optical Add-Drop Multiplexer (ROADM).

The network performance of the 400 G transmission system based on this WSS device is shown in [5]. In this work, we propose a redesign of the WSS to support high-capacity transmission for DCI applications. Specifically, we focus on two scenarios: 800 G transmission with a Free Spectral Range (FSR) of 100 GHz, employing a 64 QAM modulation format with a symbol rate of 80 GBaud, and 1200 G transmission with an FSR of 150 GHz, symbol rate of 130 GBaud utilizing a combination of L+C+S bands with 25+40+40 channels [6].

The primary objective of this study is to evaluate the performance of the WSS at the network layer in the context of DCI operations for 800 G/1200 G transmission systems. To achieve this, we assess the WSS performance in a random metro network scenario, shown in Fig. 1, simulating inter-data center transmission.

II. Networking Performance for DCI systems

In this analysis, we assess the overall network performance to analyze the impact of the 800 G and 1200 G transmission

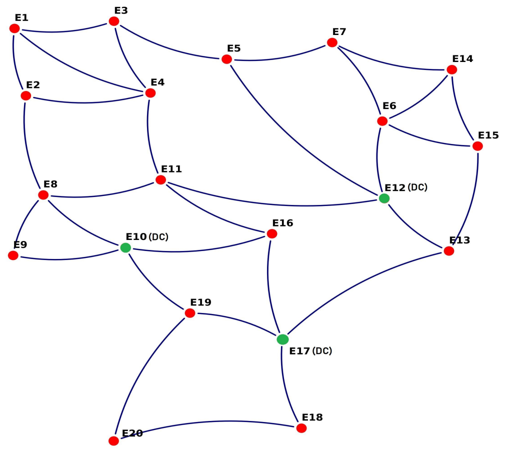

Fig. 1. Random metro topology (Green dots represents DCs)

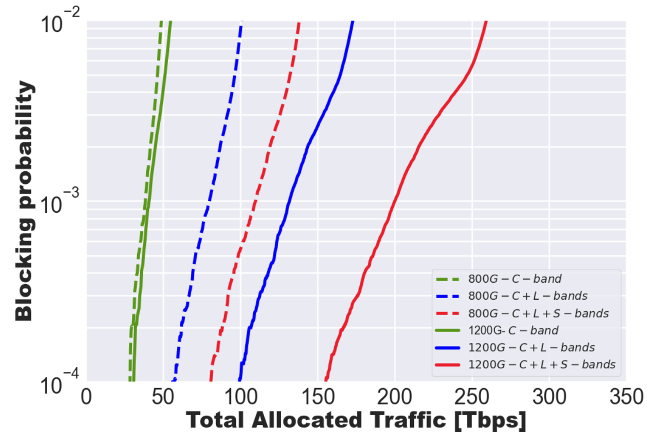

Fig. 2. BP evaluated considering ideal transceivers.

systems in DCI scenarios. To evaluate the system's performance, we employ the Statistical Network Assessment Process (SNAP) at the physical layer [7]. SNAP allows us to assess the Quality-of-Transmission (QoT) degradation caused by each network element in terms of Generalized signal-to-noise ratio (GSNR).

$$\mathrm{GSNR}_i = \frac{P_{\mathrm{S},i}}{P_{\mathrm{ASE}(f_i)} + P_{\mathrm{NLI},i}(f_i)} \tag{1}$$

where $P_{\mathrm{S},i}$ denotes the signal launch power, $P_{\mathrm{ASE}(f_i)}$ is the amplified spontaneous emission while $P_{\mathrm{NLI},i}(f_i)$ is fiber nonlinear interference [8].

To establish Lightpaths (LPs), SNAP utilizes the Routing and Wavelength Assignment (RWA) algorithm. Specifically, we employ the k-shortest routes algorithm with $k = 5$ for routing and the first-fit technique for spectrum assignment. Traffic grooming techniques are implemented to minimize the need for new LPs. We validate the availability of unused capacity in existing LPs before establishing new ones. In cases where new LPs are required, the optical controller selects the appropriate modulation format based on the estimated QoT and the required GSNR for optimal performance.

Our study assumes that optical amplifiers in a multi-band optical system, including the C- and L-band channels amplified by commercial Erbium-Doped Fiber Amplifiers (EDFAs) and the S-band channels amplified by Thulium-Doped Fiber Amplifiers (TDFAs), are tuned separately for each band. The network evaluation considers a random metro area network with an average link length of 64 kilometers and a maximum link length of 90 kilometers. The total number of nodes in the network is 20, with nodes 10, 12, and 17 designated as the Datacenter (DC) nodes randomly [9]. Traffic across all network nodes, except for the DC nodes, follows a uniform distribution. The average node degree for the network is 3.2, with a maximum node degree of 4.

III. Results

To examine the outcome of implementing the WSS structure in the design of ROADM systems, our results focus on analyzing the multi-band outcomes. We evaluate the network performance by considering two types of transceivers: 800 G and 1200 G. The plot depicted in Fig. 2 illustrates the relationship between traffic allocation and the Blocking Probabilities (BP) range for the 800 G and 1200 G transceivers.

At a BP of 10^{-2}, specifically within the C-band, the total allocated traffic for the 800 G transceiver amounts to approximately 49 Tbps. For the 1200 G transceiver, the cumulative allocated traffic slightly exceeds 55 Tbps. When considering the C+L bands, the total allocated traffic for the 800 G transceiver reaches 102 Tbps, whereas, for the 1200 G transceiver, it significantly increases to 170 Tbps, reflecting a 66% increment. Furthermore, in the case of C+L+S bands, the total allocated traffic for the 800 G transceiver is 140 Tbps, while for the 1200 G transceiver, it rises to 260 Tbps, denoting an 84% increase. The substantial growth can be attributed to the total spectrum/bandwidth allocation. In the case of the 800 G transceiver, the spectrum assigned for all three bands (C, L, and S) amounts to 4 THz. On the other hand, for the 1200 G transceiver, the spectrum allocation differs, with 6 THz designated for the L and S bands, and approximately 4 THz allocated for the C-band.

Fig. 3 presents the overall traffic allocation per link for both the 800 G and 1200 G scenarios. The 'E11-E12' link demonstrates the highest traffic allocation in the 800 G case, reaching approximately 4100 Gbps. In comparison, the same link exhibits the highest traffic allocation in 1200 G case, amounting to 7550 Gbps. The horizontal dotted line represents 50% of the total allocated traffic, normalized for each case (800 G/1200 G). Notably, the data centers are positioned at E10, E12, and E17, and all links surpassing the 50% threshold are primarily associated with these data centers.

Fig. 4 illustrates the total number of channel allocations for both the 800 G and 1200 G scenarios. In the 800 G case, there are a total of 120 channels, while in the 1200 G case, the total number of channels amounts to 105. The dotted lines indicate the 75% threshold of the total channels for each respective case. Notably, for the 'E11-E12' link, which exhibited the highest traffic allocation in Figure Fig. 3, the channel allocation reaches its maximum capacity for both the

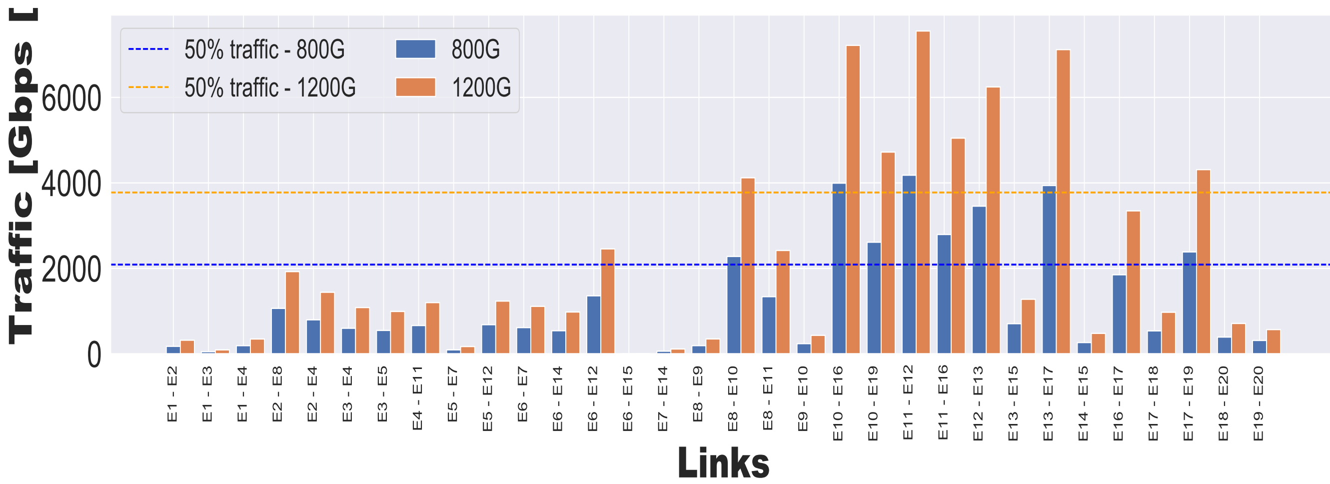

Fig. 3. Traffic allocation / link

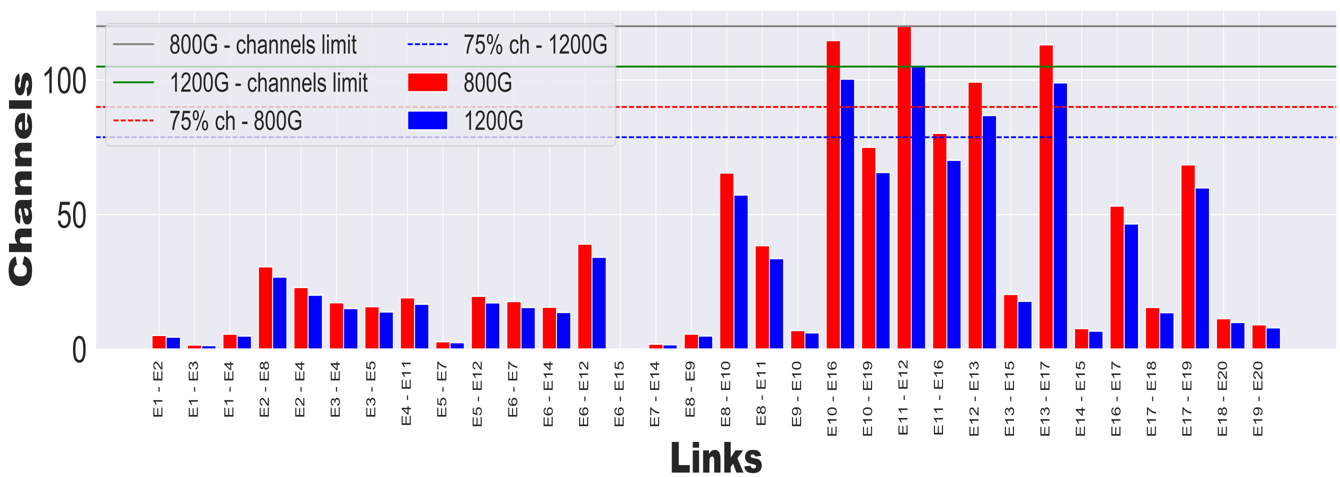

Fig. 4. Channel allocation / link

800 G and 1200 G cases. Additionally, all the links that surpass the 75% channel allocation threshold are directly associated with the data center nodes.

IV. Conclusion

This study evaluated the networking performance of a modular photonic integrated wideband WSS intended to facilitate multi-band operation in DCI systems. Our work compared the channel distribution and traffic link allocation between the 800 G and 1200 G transceivers. Our results show that better traffic distribution is produced by transceivers with increased capacity. Our study provides valuable insights into improving network configurations to optimize capacity and improve overall network performance by thoroughly analyzing traffic and channel allocation.

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