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# A Comprehensive Network Performance Analysis of Multi-band Photonic Integrated WSS for 400G and 800G Transmission

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**ABSTRACT** Bandwidth-intensive applications require an increase in the capacity of optical transport networks. One solution is multi-band transmission, which leverages low-loss optical spectrum windows to enhance network capacity without requiring new fiber infrastructure or significant capital expenditure. This study uses a Reconfigurable-Optical-Add-Drop-Multiplexer (ROADM) architecture utilizing a modular photonic integrated multi-band Wavelength-Selective-Switch (WSS) for multi-band transmission. The WSS architecture is assessed through a comprehensive network performance analysis, examining transceivers 400G and 800G, on real USA network topology. The study demonstrates the potential advantages of shifting from traditional C-band transmission to multi-band transmission in terms of network performance.

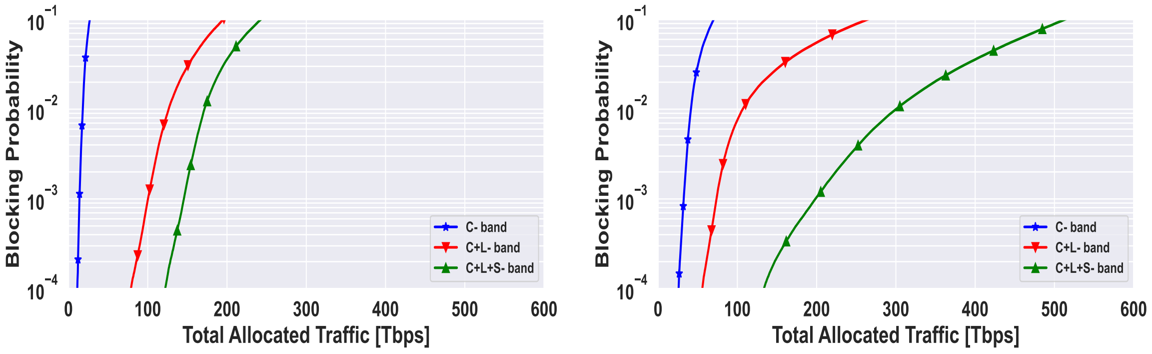
**Keywords:** Multi-band, Photonic Integrated Circuits, Wavelength-Selective-Switch, Networking analysis

## 1. INTRODUCTION

The projected Compound Annual Growth Rate (CAGR) for worldwide Internet usage is 30% [1]. A substantial increase in cellular network capacity due to the implementation of 5G technology is expected, requiring the use of fiber networks for optical transmission in all other network segments. Network providers must develop scalable, affordable, and flexible strategies to increase the capacity of their existing infrastructure in order to meet this growing demand. These measures are essential for ensuring the Internet's long-term dependability and efficacy. The current optical infrastructure for Wavelength Division Multiplexing (WDM) relies on the C-band, which has a bandwidth of 4.8 THz, to transmit data from long-haul/submarine to urban networks using a preferred PM-16QAM modulation scheme, resulting in transfer rates of approximately 30 Tbps per fiber. However, expanding capacity by installing new fiber can be costly, mainly when fiber resources are scarce. Multi-band transmission has been proposed as a potential solution to increase network capacity by transmitting data across a wider spectrum of optical fiber spectral bandwidths with low loss to address this issue. Stimulated Raman Scattering (SRS) may cause transmission degradation and imbalances. Therefore, evaluating the overall performance of a network requires a careful comparison of multi-band and single-band transmission systems.

There are two potential strategies to expand the optical network equipment capacity in this context. The first is Spatial Division Multiplexing (SDM) which utilizes Multicore (MCF), Multimode (MMF), or Multiparallel (MPF) fibers. Band Division Multiplexing (BDM) is a technique that utilizes a broader range of optical fibers to facilitate transmission with low loss. For instance, ITU G.652.D fibers can transmit up to 54 THz. The deployment of SDM solutions, such as MCF and MMF, requires a comprehensive overhaul of the optical transport infrastructure, encompassing novel fibers and devices. On the contrary, the use of BDM presents a practical solution for augmenting the optical network's capacity without necessitating supplementary optical fibers. Although optical amplification presents the greatest challenge for the BDM system, several prototype amplifiers that operate in the extended-spectrum area are now readily accessible [2]. Transparent wavelength routing in BDM requires filtration and switching elements like WSS. These parts allow input channels to be autonomously managed and routed to the WDM comb fiber output. Typically, Liquid Crystal on Silicon (LCoS) and Microelectronic mechanical Systems (MEMS) are the bulky and complicated technologies commonly used in the construction of WSS devices [3].

The study conducted in this article involved the utilization of Photonic Integrated Circuits (PICs) technology for the implementation of a modular multi-band WSS [4]. This approach differs from the conventional WSS systems that rely on MEMS and LCoS technologies, which are bulky in nature. The modular architecture of the suggested WSS enables it to function over a large portion of the optical spectrum, including the C+L+S bands. Furthermore, it can support a greater number of output fibers and channels while occupying a smaller physical footprint than conventional MEMS-based alternatives. The architecture only considers the WSS module's switching functionality without considering the local add/drop module of the ROADM. The network performance of the multi-band modular WSS is assessed through its operation with a 16QAM modulation format, symbol rate of 60 GBaud, and a Free Spectral Range (FSR) of 100 GHz WDM comb (40 channels per band), which facilitates 400G long-range transmission, as reported in [5], [6]. The present research suggests a reconfiguration of the Wavelength Selective Switch (WSS) to facilitate 800G transmission, featuring an FSR



(a) Blocking probability evaluated considering 400G transceiver

(b) Blocking probability evaluated considering 800G transceiver

*Figure* 1: Total traffic allocation vs blocking probability for 400G/800G transceivers

of 150 GHz (comprising 25 channels in the C- band and 40 channels per band in the L- and S- band) and a 16QAM modulation format with a symbol rate of 120 GBaud [7]. Subsequently, the study assesses the WSS's efficacy at the network layer. A comprehensive networking analysis compares the 400G and 800G transceivers utilizing the PIC-based WSS architecture.

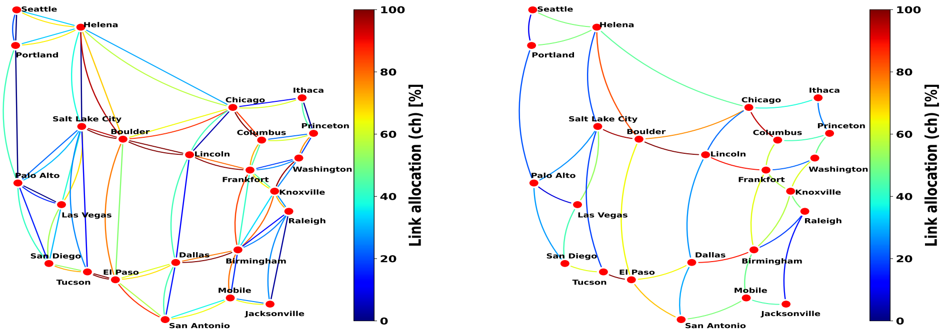
## 2. NETWORK EFFICIENCY ASSESSMENT

We evaluated the network's overall performance and the impact of the modular WSS architecture on optical transport methods using the Statistical Network Assessment Process (SNAP) tool [8]. SNAP operates on the network's physical layer and considers the Quality-of-transmission (QoT) degradation caused by each component. We assume that the optical line system employs a three-band () design with customized network elements for each band, such as optical amplifiers. More specifically, we anticipate that all enhanced line fibers will use normal single-mode fiber and be 75 km long. (ITU-T G.652D). Regarding the amplifiers, commercially available Erbium-doped fiber amplifiers (EDFA) are being considered for the C- and L-band channels, while Thulium-doped fiber amplifiers (TDFA) are being considered for the S-band. To allocate Light-paths (LPs) in our network, we utilize the Routing and Wavelength Allocation (RWA) technique. This involves selecting the $k$ shortest routes with a maximum of $k = 5$ for routing and using the first-fit method for spectrum allocation. Traffic grooming is applied, and it aims to minimize the necessity for creating new LPs by verifying whether there is any unused capacity in the current LPs. In the event that a new LP needs to be established, the optical controller selects the appropriate modulation format based on the estimated Quality-of-Transmission (QoT) and the Required Generalized Signal to Noise Ratio (RGSNR) for optimum performance. Additionally, we evaluate network performance using homogenous traffic of 100 Gbps between nodes. We use the USA topology for our performance evaluation, which includes 43 edges and 24 optical nodes. To define the network's statistical characteristics, we employ Monte Carlo analysis.

## 3. RESULTS AND DISCUSSION

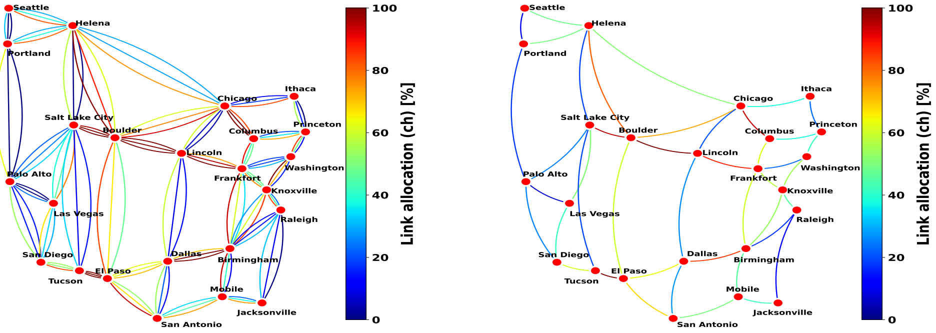
In order to analyze multiband outcomes when employing the WSS structure within the ROADM design, we assess the network performance using two different kinds of transceivers, 400G and 800G. Due to the availability of more modulation levels and greater baud rates, it is feasible to accomplish a reduced cost per bit using higher capacity transceivers. We compare the 400G and 800G transceivers in our study, limiting the highest modulation format to 16QAM for both cases to ensure a fair comparison. Two transceivers—400G and 800G—have been used in simulations of the USA network topology for the multi-band scenario. The network-level analysis is carried out using the optimized transmission findings, and a topological graph is made using the GSNR values for each WDM channel. In order to execute SNAP, this graph is then weighted based on the Generalized signal-to-noise ratio (GSNR) degeneration.

Fig. 1 (a) and (b) represents the total allocated traffic vs. the Blocking probability (BP) for both the cases of 400G and 800G transceivers, respectively. In Fig. 1(a), when BP = $10^{-1}$, the C-band allocated approximately 35 Tbps of traffic, while the total traffic allocation for the C+L-band was around 200 Tbps. By activating all three bands, C+L+S, the total traffic allocation increased to 240 Tbps. In Fig. 1(b), with BP = $10^{-1}$, the C-band only allocated approximately 80 Tbps of traffic, whereas, for the C+L-band, the total traffic allocation was around 280 Tbps. When all three bands, C+L+S, were activated, the total traffic allocation for the 800G transceiver case exceeded 500 Tbps. Furthermore, BDM and SDM networks are compared using two transceiver cases in a multi-band context. Using SNAP network performance analysis, our study evaluated SDM networks with multiple



(a) SDM (C-band, 2x fibers)

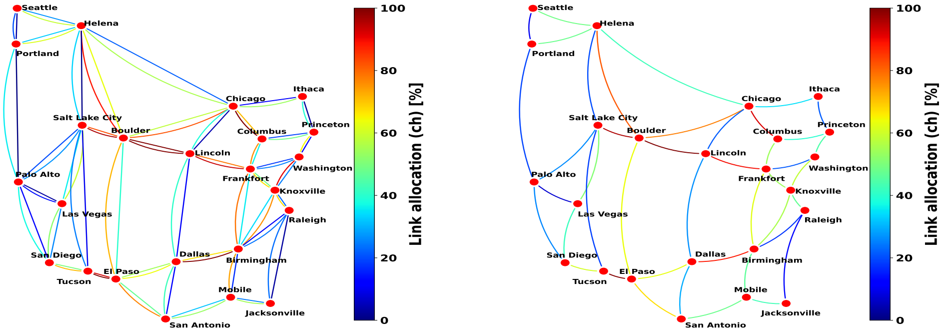
(b) BDM (C+L-band, 1x fiber)



(c) SDM (C-band, 3x fibers)

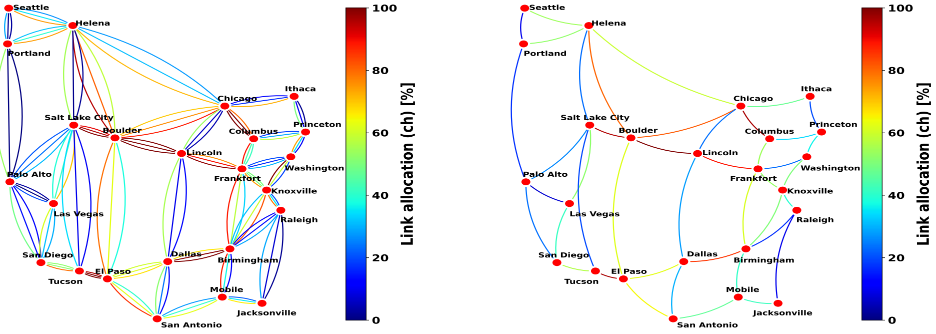
(d) BDM (C+L+S-band, 1x fibers)

*Figure* 2: Channel allocation using 400G transceiver



(a) SDM (C-band, 2x fibers)

(b) BDM (C+L-band, 1x fiber)



(c) SDM (C-band, 3x fibers)

(d) BDM (C+L+S- band, 1x fibers)

*Figure* 3: Channel allocation using 800G transceiver

TABLE I: SDM vs. BDM link allocation details

| Link allocation (channel) % | | | | |
|---|---|---|---|---|
| **Transceiver** | **C-band, 2x fibers** | **C+L- band** | **C-band, 3x fibers** | **C+L+S band** |
| 400G | 45.78 | 44.92 | 47.59 | 46.83 |
| 800G | 49.87 | 48.73 | 50.11 | 48.55 |

C-band fibers and the same total spectrum. BDM used multi-bands, including C+L and C+L+S. For the 400G transceiver case, we evaluated 40 channels per band. In comparison, in the case of the 800G transceiver, we reduced the number of channels in the L- and S-bands to 25, corresponding to the C-band's maximum capacity at 150GHz spacing. Table I displays the link allocation, in terms of channels, for both transceiver cases in both SDM and BDM scenarios. The multi-band BDM scenario has slightly lower channel allocation in both network scenarios than the single-band SDM scenario. However, in the case of SDM with three fibers and multi-band BDM (bands), the difference between SDM and BDM increases slightly due to nonlinear propagation caused by transmitting all three bands on a single fiber.

## 4. CONCLUSION

The study shows that reduced cost per bit is associated with greater capacity transceivers and that the 800G transceiver outperforms the 400G transceiver in terms of traffic allocation. Additionally, comparing the C-band (2x, 3x fiber) with the C+L- and C+L+S- bands while keeping the same number of channels for each band in each transceiver for a fair assessment of multi-band provides valuable insights into optimal network configurations for maximizing network capacity and performance.

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