Environmental Impact of Coherent Point-to-Multipoint Pluggables in Metro Aggregation Optical Networks

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***Abstract*—The environmental impact of telecommunications is becoming increasingly relevant in our society as more data are transmitted every day. On the one hand, telecommunication networks help, for example, by reducing the number of travels and visits; on the other hand, the energy consumed by the network elements and devices is reaching unprecedented levels as a consequence of the growing bandwidth demand needed by novel applications and services. In this contribution, we analyze key metrics to estimate the energy efficiency, in building an optical network, of several types of optical transceivers when employed in the most common topologies of metro aggregation networks, i.e., horseshoes, rings, and hub-and-spoke. We considered three different types of coherent pluggable modules: (i) 400G ZR point-to-point (P2P); (ii) 400G ZR+ P2P; and (iii) 100G/400G point-to-multipoint (P2MP) which can be enabled by digital subcarrier multiplexing (DSCM). We show that the P2MP approach needs—due to its inherent flexibility and the ability to simplify network design—the lowest number of devices, and consequently the lowest amount of CO_2 emissions among the three considered metro aggregation network scenarios.**

***Index Terms*—Point-to-multipoint optical network, coherent technology, optical aggregation, digital subcarrier multiplexing**

I. Introduction

The energy demand of telecommunication operators is currently estimated to account for 3–5% of the global demand. By considering a plausible 30% capacity annual growth rate– as the increase in connectivity and data rates shows no signs of slowing down– it is predicted that power consumption will triple by 2030 [1]. In addition, electronic waste (E-waste)—electronic devices, circuit boards, and other electronic components that are replaced and dismissed—is becoming a major threat to the environment, since these discarded devices often pile up in landfills and further pollute soils and water supplies with toxic material. Only in 2019, the world discarded 53.6 million tons of E-waste according to the United Nations [2], an increase of 21% compared to 2014. At this rate, the amount of E-waste will double in just 16 years. The causes behind these extreme numbers depend on a myriad of aspects, such as (i) the need to replace outdated devices due to security concerns or inter-generational incompatibility, (ii) the significant increase in the number of mobile electronic and Internet-connected devices, and (iii) the proliferation of storage and compute systems. In this study, we explore an environment-oriented strategy that can be utilized to reduce E-Waste and CO_2 emissions by redesigning network architectures to better match traffic patterns in the fastest growing markets. This effect can be achieved, for example, by deploying technologies that require a smaller number of transceivers so that both the number of devices to be recycled and the power consumption—and thus CO_2 emissions—can be lowered. The environmental impact can be reduced even further by a technology that can enable software configurable pay-as-you-grow capacity management and provisioning and inter-generational compatibility of transceivers [3].

Telecommunications networks have leveraged the benefits of Point-to-Multipoint (P2MP) optics—realized with Intensity Modulation Direct-Detection (IM-DD) transceivers—for decades both in Passive Optical Networks (PONs) (single Optical Line Termination (OLT) to many Optical Network Units (ONUs)) and within data centers (breakout cables in the spine and leaf configuration) [4]–[6]. On the one hand, this P2MP solution has enabled the diffusion of broadband connectivity and allowed a reduction in power consumption, footprint, and Capital Expenditure (CAPEX). On the other hand, when moving beyond 50G-PON, coherent solutions might be needed to overcome the physical limitation of IM-DD-based transceivers [3], [7].

In metro aggregation networks, there has been a misalignment between actual traffic patterns and underlying technology used to transport data across them. For example, in this segment, traffic is overwhelmingly Hub-and-Spoke (H&S), with a myriad of low data rate transceivers communicating to a few hubs operating at high data rate; however, optical connectivity has been mainly realized using Point-to-Point (P2P) technology in networks other than PONs. This is a sub-optimal network architecture that requires a large number of bookended transceivers as part of the aggregation stage, in addition to numerous intermediate aggregation devices to "up-speed" traffic flows [8].

An alternative approach would be to broadcast/narrowcast

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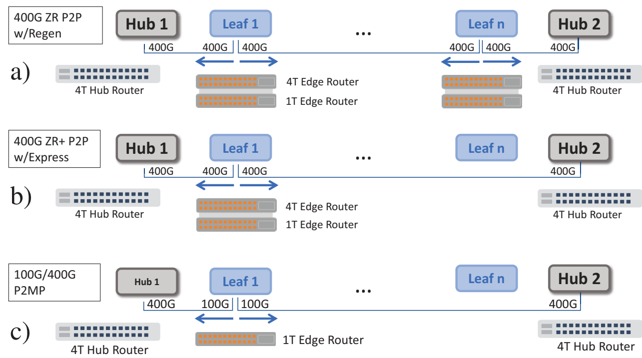

Fig. 1: Example of a horseshoe network architecture realized with the considered coherent-based approaches: a) using 400G ZR P2P w/Regen, b) using 400G ZR+ P2P w/Express, and c) using 100G/400G P2MP with Digital Subcarrier Multiplexing (DSCM).

the data traffic. In this scenario, several end sites could transmit/receive traffic to/from a hub over a simple broadcast architecture using passive splitter/combiner devices [9]. This solution, based on DSCM [3], enables a single transceiver to generate multiple lower-speed subcarriers that can be independently steered to different destinations, allowing P2MP and low-speed-to-high-speed connectivity [3]. As a result, the number of transceivers and routers can be greatly reduced, thus decreasing the amount of E-waste, while also leading to lower power consumption and CO_2 emissions. Fig. 1 reports on one of the network architectures considered in this study and the different coherent transceivers used to evaluate energy savings: 400G ZR P2P w/Regen [10], 400G ZR+ P2P w/Express [11], and 100G/400G P2MP [3].

In this article, we address the environmental impact of the aforementioned solutions for common network topologies such horseshoes, rings and H&S. Here, we estimate the number of needed devices and quantify the order of magnitude of the amount of CO_2 emissions for the different solutions. The remainder of the article is structured as follows: Sec. II introduces the concept of P2MP transceivers, while Sec. III describes the model and the analysis. Sec IV deals with the results and final Sec. V draws the conclusions.

II. Point-to-multipoint transceivers

In access and metro networks, the potential of P2MP-based optical communications can be realized using DSCM-powered pluggable transceivers [3]. These devices create virtual channels—transmitting, for instance, in slots of 25 Gb/s (25G)—that match the traffic patterns typically exhibited within these networks. In case P2P transmission is needed, these devices can also operate in a P2P mode.

Moreover, from a technology point of view, DSCM offers clear advantages over competing P2MP approaches such as Orthogonal Frequency-Division Multiplexing (OFDM) [12] or Sliceable Bandwidth Variable Transponders (S-BVTs) [13], in the form of improved tolerance to channel distortions [14]–[16] or resource sharing. For scenarios where P2MP is more suitable, 16 Nyquist Subcarriers (SCs), each one operating at 4 GBd, enable the implementation of up-to 400G traffic solutions, assuming 16-Quadrature Amplitude Modulation (QAM) as modulation format and polarization-multiplexing as a transmission scheme [3]. As a transmitter in a downlink scenario, a P2MP transceiver produces a ∼64 GHz-wide 400 Gb/s Wavelength Division Multiplexing (WDM) signal with 16 SCs, which is optically broadcast to the network. Based on the DSCM technology and combined with modern coherent Digital Signal Processing (DSP), a given receiver can extract its intended SCs from the WDM spectrum and process them accordingly. In this way, a single hub node can communicate with multiple leaf nodes, which can have different data rate requirements. For example, a single 400G P2MP hub transceiver could communicate with up to 16 leaf nodes simultaneously at 25G for each connection. In the uplink, the groups of SCs may have different origins and optical paths to the hub node. Therefore, DSP must be sufficiently robust to compensate for distortions while also providing tolerances due to the slight differences in terms of impairments among SCs to successfully decode the data. In this regard, as a P2MP solution does not require the use of bookended transceivers in the networks, which might cause over-provisioning and in turn translate into large expenses, but instead fosters a novel network paradigm in which low-speed-to-high-speed transceiver communication is possible and desired. This has a direct impact on cost, as a P2MP solution allows for a pay-as-you-grow model [8], [9]. Ultimately, the reduced number of transceivers results in lower power consumption, which decreases the carbon and environmental footprint of the network.

III. Modeling and Analysis

For the techno-economic analysis, we have considered different types of networks: (i) horseshoe, (ii) ring, and (iii) an H&S; where traffic is considered symmetric. For the horseshoe network, each leaf node transmits the same amount of data to both hubs (see Fig. 2). Similarly, for the ring network, each node transmits the same amount of data to the given end hub through both ends of the ring structure (see Fig. 3). Regarding the H&S network, a single hub is used to terminate traffic from all leaf sites (see Fig. 4). The size of traffic from one leaf site can be different from that from another. For each network configuration, we have modeled three scenarios according to the number of leaf nodes per network—5, 9, and 12 nodes—, where we consider dual hubs (for horseshoe and ring only) and duplicate hardware at leaf sites for redundancy purposes. The initial conditions for the traffic from the leaf node(s) to the hub(s) are set to 100G, and we assume a traffic growth of 100G per year per leaf node, which corresponds to a total of 38% CAGR over a 5-year period in line with analyst reports. The traffic analysis performed in this study obeys the following profile: odd leaf sites (i.e. 1, 3, ..., 11) transmit 1×100G to the hub(s), while even leaf nodes (i.e. 2, 4, ..., 12) transmit 2×100G to the hub(s). For each type of network and for each scenario (i.e. 5, 9, and 12 leaf nodes), we compared three different coherent-based approaches: 400G

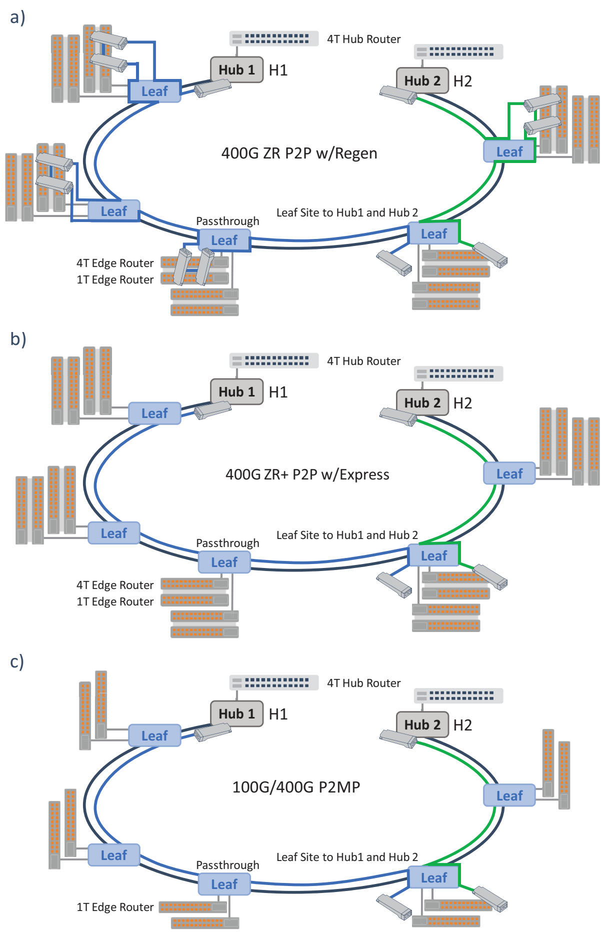

Fig. 2: Considered horseshoe network configurations a) 400G ZR P2P w/Regen, b) 400G ZR+ P2P w/Express, and c) 100G/400G P2MP.

ZR P2P w/Regen [10], 400G ZR+ P2P w/Express [11], and 100G/400G P2MP [8].

In horseshoe or ring configurations, the traffic between the source and destination is regenerated at the intermediate leaf sites using 400G ZR pluggables. In the 400G ZR+ P2P w/Express solution, traffic is optically expressed at the intermediate leaf sites, taking advantage of the higher optical performance of 400G ZR+ [11]. From a line system perspective, this can be implemented in several ways, including the use of fixed or reconfigurable optical add/drop multiplexers or a filterless line system with passive couplers and combiners. Both 400G ZR w/Regen and 400G ZR+ w/Express operate in a P2P configuration along the horseshoe ring. However, a single 400G ZR P2P pluggable can "regen" multiple 100G streams, and it is assumed that a dual-router setup (4 Terabit (4T) for 400G and a 1T router for lower speeds, interconnected with grey optics) provides a lower granularity of service. In our proposed solution (100G/400G P2MP), to better match the H&S traffic, a 400G P2MP transceiver is deployed at each hub site, while 100G P2MP pluggables are introduced at the remote leaf nodes. Given the 25 Gb/s granularity, a single 1T router is assumed at each leaf node. Our transport layer

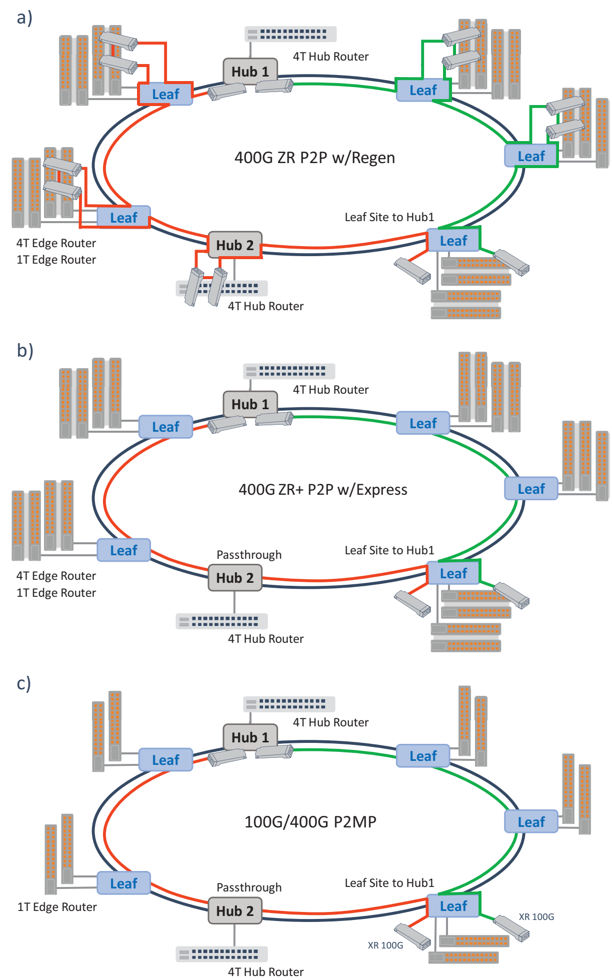

Fig. 3: Considered ring network configurations a) 400G ZR P2P w/Regen, b) 400G ZR+ P2P w/Express, and c) 100G/400G P2MP.

analyses cover two aspects: (i) number of telecom devices used in each setup to assess the impact on E-waste and (ii) CO_2 emissions,. The investigation has been carried out for 400G ZR P2P w/Regen, 400G ZR+ P2P w/Express, and 100G/400G P2MP as described in Fig. 2 (a–c) (horseshoe architecture), Fig. 3 (a–c) (ring architecture), and Fig. 4 (a–b) (H&S architecture).

IV. Results and Discussion

The main assumptions used in this analysis are listed hereafter: (i) 400G ZR+ P2P w/Express has the same power consumption as 400G P2MP; (ii) 400G ZR P2P w/Regen has the same power consumption as 100G P2MP; (iii) The power consumption of a 4T router (10×400G ports) at hub sites is the same as that of a 4T mix router at the leaf sites; and finally (iv) the power consumption of a 1T router is 10% of a 4T router. The results of our network study are reported in Fig. 5 for the horseshoe, in Fig. 6 for the ring, and in Fig. 7 for the H&S.

Number of devices: Due to E-waste, toxins can enter the soil and water supplies and contaminate the environment.

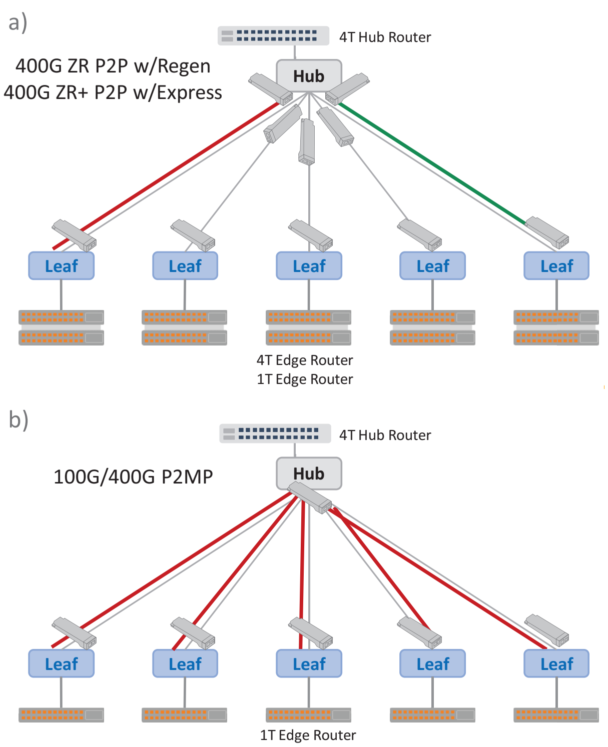

Fig. 4: Considered H&S network configurations a) 400G ZR P2P w/Regen, b) 400G ZR+ P2P w/Express, and c) 100G/400G P2MP.

Consequently, we compare the total number of electronic devices (routers, grey and coherent pluggables) in the three aforementioned network scenarios. The lower the number of devices used, the better for the environment.

Our analysis reveals that the number of devices, when using 400G ZR P2P w/Regen, increases significantly with traffic growth (Fig. 5 (a) and Fig. 6 (a)). In horseshoe and ring configurations, this can be explained by the fact that all traffic streams must be regenerated at each intermediate site; hence, there is a considerable increase in the number of coherent pluggables as traffic grows. Furthermore, increasing the number of leaf sites also impacts the number of devices, since each additional leaf site will be required to "regen" the traffic, thus driving the need for more routers and 400G ZR P2P pluggables. We also notice that the gap between 100G/400G P2MP and 400G ZR+ P2P w/Express is smaller than the gap between 100G/400G P2MP and 400G ZR P2P w/Regen given the latter fewer coherent pluggable compared to 400G ZR P2P w/Regen (no regeneration is required at the intermediate leaf site). However, 400G ZR+ P2P w/Express uses higher count of routers given its granularity of 400G compared 100G/400G P2MP's granularity of 25G. For the H&S configuration (Fig. 7 (a)), the number of devices for 400G ZR+ P2P w/Express and 400G ZR P2P w/Regen is the same since both require the same number of routers, grey and coherent pluggables. In this configuration, we notice that 100G/400G P2MP requires on average 50% fewer devices than 400G ZR+ P2P w/Express and 400G ZR P2P w/Regen.

Power consumption and carbon dioxide (CO_2) emissions: Typically, electricity in a given country is generated by various sources (e.g. petroleum, natural gas, coal, etc.), which provide different amounts of energy to the country's electrical grid: while some nations rely mainly on coal, others prefer to utilize natural gas or renewable energies as less polluting alternatives. As CO_2 emissions are largely related to power consumption, in order to estimate the carbon footprint of a given network configuration, we have to add up the contributions from the routers and all coherent pluggables in the scenarios considered. Our calculations suggest a beneficial impact of 100G/400G P2MP transceivers in horseshoe configurations, as they reduce power consumption by $\sim$75% compared to 400G ZR+ P2P w/Express and 400G ZR P2P w/Regen, since fewer routers and pluggables are needed at the hub sites [9]. Furthermore, the finer granularity of 400G P2MP allows us to deploy smaller and more power efficient routers at leaf sites compared to the alternative approach, which required two interconnected/stacked routers (4T and 1T) for higher-speed and lower-speed communication, respectively. Additionally, a single coherent 400G P2MP pluggable can be connected to a maximum of 16 leaf nodes simultaneously at a data rate of 25G per leaf, thus reducing the number of interfaces at the hub sites. We also notice that, as the traffic and the number of leaf sites increase, the power consumption gap between 100G/400G P2MP and 400G ZR P2P w/Regen widens significantly; especially in Y5 when a horseshoe network with 12 leaf sites is modeled. This can be explained by the excessive number of 400G ZR P2P pluggables that have to be deployed at intermediate sites to regenerate the terminating and digitally passthrough traffic. In a ring configuration, the results are similar to the horseshoe configuration. Here, the 100G/400G configuration with P2MP reduces power consumption up to 89% when 12 leaf nodes are analyzed. For H&S configuration, on the other hand, traffic is not regenerated as there are no intermediate nodes. For this reason, the number of coherent pluggables for 400G ZR+ P2P w/Express and 400G ZR P2P w/Regen solutions is the same. Moreover, the number of routers for both configurations is also the same. 400G ZR+ P2P w/Express, however, has a slightly higher consumption than 400G ZR P2P w/Regen due to the fact that 400G ZR pluggables consume less power than 400G ZR+ pluggables (15 W versus 25 W, respectively).

To assess the carbon footprint of a network in relation to consumed power, we have used data from the US Energy Information Administration (EIA) [17] to estimate CO_2 emissions according to energy source: 1.012 kg/kWh corresponds to coal, 0.413 kg/kWh is the value for natural gas, and 0.966 kg/kWh denotes petroleum. For this study, we have also assumed different weights (i.e. contribution percentage) for the electricity generated from coal (30%), natural gas (30%), and petroleum (40%) according to [17][1]. The results showing the estimated CO_2 emissions as a function of the number

[1] Some countries may rely more on one source versus the other. We believe that the split 30%, 30%, 40% represents a good assumption.

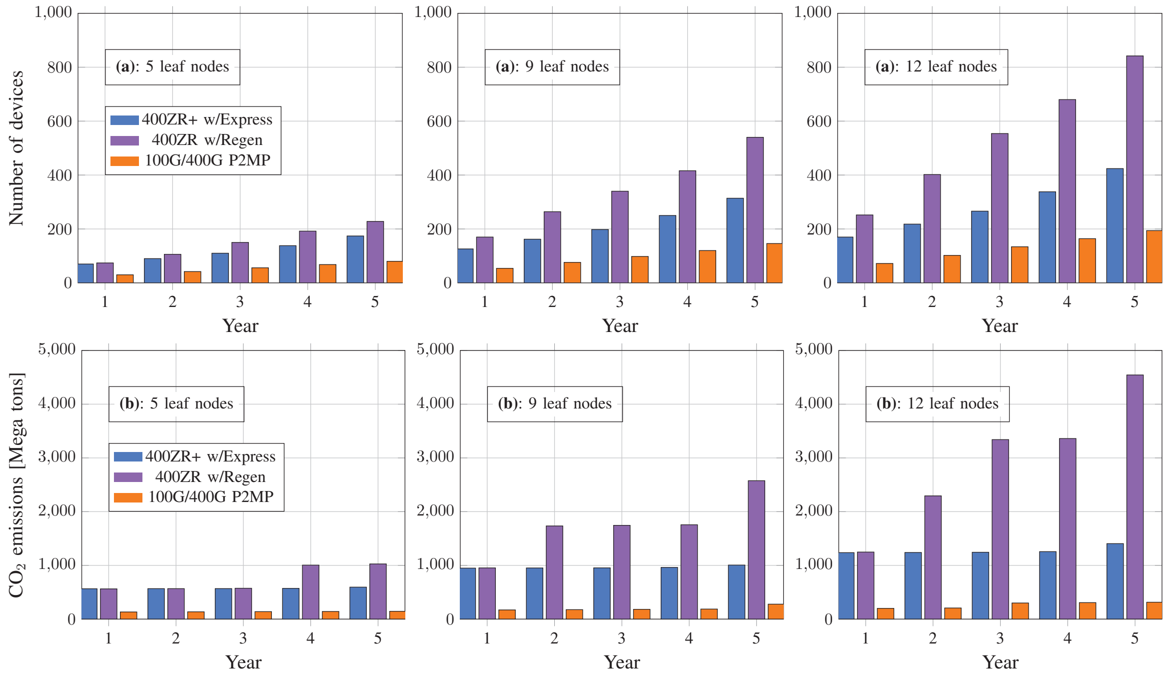

Fig. 5: Comparison over 5 years for 5, 9, and 12 leaf nodes for 400G ZR P2P w/Regen, 400G ZR+ P2P w/Express, 100G/400G P2MP in horseshoe configuration: (a) Number of devices; (b) CO_2 emissions [Mega tons].

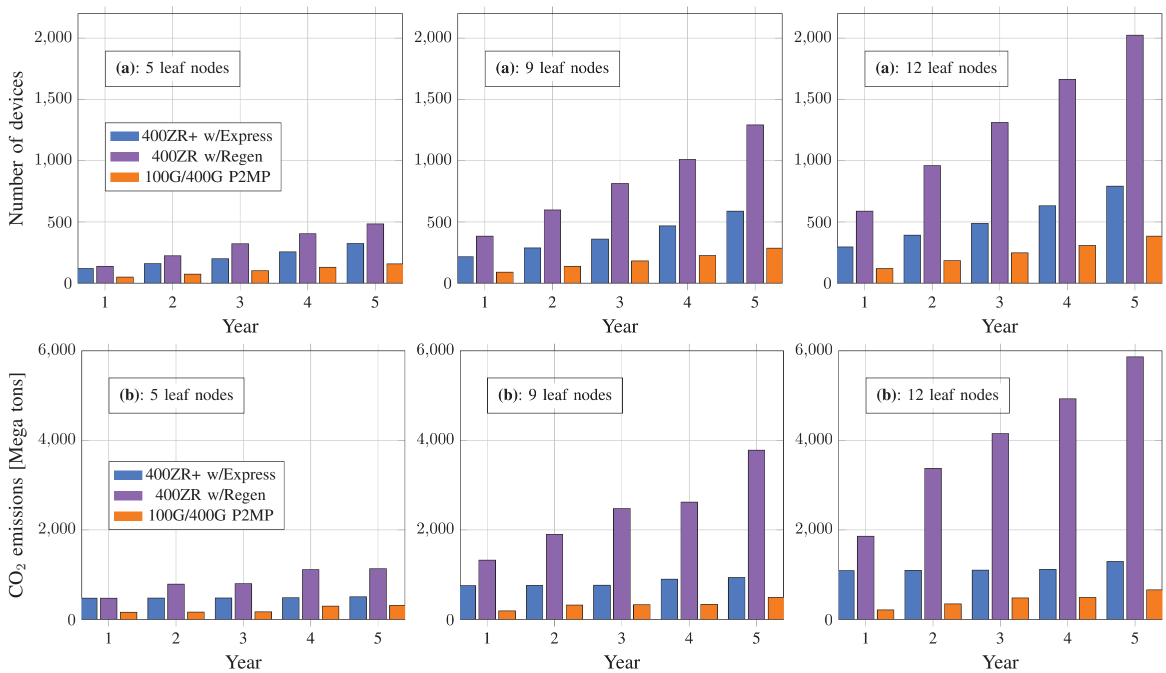

Fig. 6: Comparison over 5 years for 5, 9, and 12 leaf nodes for 400G ZR P2P w/Regen, 400G ZR+ P2P w/Express, 100G/400G P2MP in ring configuration: (a) Number of devices; (b) CO_2 emissions [Mega tons].

of nodes and growth for the various scenarios are depicted in Fig. 5 (b) (horseshoe architecture), Fig. 6 (b) (ring architecture), and Fig. 7 (b) (H&S architecture). Based on these analyses, we can conclude that solutions powered by 100G/400G P2MP pluggables undoubtedly exhibit the lowest amount of CO_2 emissions among the approaches we have considered and investigated.

V. Conclusions

Reducing power consumption, CO_2 emissions, and E-waste are essential to ensure a greener impact on the planet. Ad-

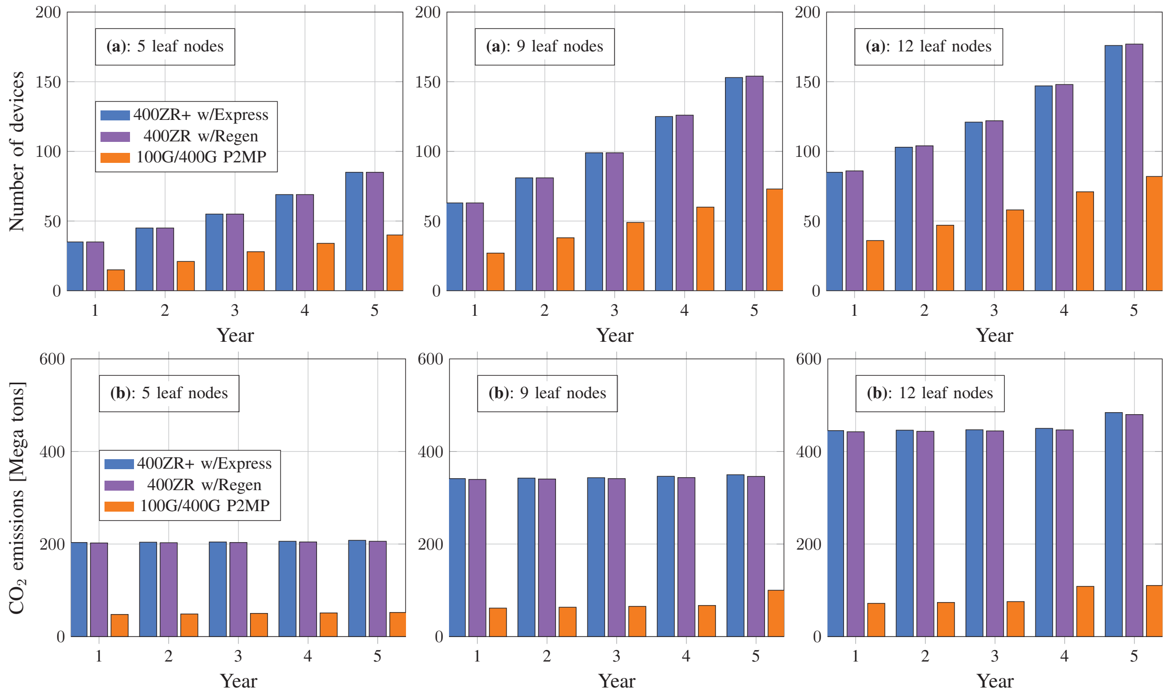

Fig. 7: Comparison over 5 years for 5, 9, and 12 leaf nodes for 400G ZR P2P w/Regen, 400G ZR+ P2P w/Express, 100G/400G P2MP in H&S configuration: (a) Number of devices; (b) CO_2 emissions [Mega tons].

vances in coherent optical technologies and new network architectures can be game changers in making positive contributions to global initiatives toward a greener and cleaner habitat for future generations. We considered three different types of network architectures: horseshoe, ring, and hub-and-spoke. We evaluated the number of transceivers needed and CO_2 emissions for the three cases when using 400G ZR point-to-point, 400G ZR+ point-to-point, and 100G/400G point-to-multipoint. The analyses show that the latter provides better results, thanks to its inherent flexibility and scalability. Future studies will consider time-varying traffic profiles and real-life networks, and the potentialities enabled by digital subcarrier multiplexing in terms of dynamic capacity allocation.

References

[1] "Telecoms to Triple Electricity Consumption, Boosting Growth of Distributed Energy Generation [checked on Oct, 14th 2022]."

[2] "Global E-Waste Surging: Up 21% in 5 Years [checked on Oct, 14th 2022]." https://unu.edu/media-relations/releases/global-e-waste-surging-up-21-in-5-years.html#info/.

[3] D. Welch, A. Napoli, J. Bäck, S. Buggaveeti, C. Castro, A. Chase, X. Chen, V. Dominic, T. Duthel, T. A. Eriksson, *et al.*, "Digital subcarrier multiplexing: Enabling software-configurable optical networks," *Journal of Lightwave Technology*, 2022.

[4] "ITU-T PON standards - progress and recent activities." https://www.itu.int/en/ITU-T/studygroups/2017-2020/15/Documents/OFC2018-2-Q2_v5.pdf.

[5] R. Bonk, D. Geng, D. Khotimsky, D. Liu, X. Liu, Y. Luo, D. Nesset, V. Oksman, R. Strobel, W. Van Hoof, *et al.*, "50G-PON: The First ITU-T Higher-Speed PON System," *IEEE communications magazine*, vol. 60, no. 3, pp. 48–54, 2022.

[6] T. Pfeiffer, P. Dom, S. Bidkar, F. Fredricx, K. Christodoulopoulos, and R. Bonk, "PON going beyond FTTH [invited tutorial]," *Journal of Optical Communications and Networking*, vol. 14, no. 1, pp. A31–A40, 2022.

[7] M. Xu, Z. Jia, H. Zhang, L. A. Campos, and C. Knittle, "Intelligent burst receiving control in 100G coherent PON with 4× 25G TFDM upstream transmission," in *Optical Fiber Communication Conference*, pp. Th3E–2, Optica Publishing Group, 2022.

[8] D. Welch, A. Napoli, J. Bäck, W. Sande, J. Pedro, F. Masoud, C. Fludger, T. Duthel, H. Sun, S. J. Hand, *et al.*, "Point-to-multipoint optical networks using coherent digital subcarriers," *Journal of Lightwave Technology*, vol. 39, no. 16, pp. 5232–5247, 2021.

[9] J. Bäck, P. Wright, J. Ambrose, A. Chase, M. Jary, F. Masoud, N. Sugden, G. Wardrop, A. Napoli, J. Pedro, *et al.*, "CAPEX savings enabled by point-to-multipoint coherent pluggable optics using digital subcarrier multiplexing in metro aggregation networks," in *2020 European Conference on Optical Communications (ECOC)*, pp. 1–4, IEEE, 2020.

[10] "Implementation agreement 400ZR." https://www.oiforum.com/wp-content/uploads/OIF-400ZR-01.0_reduced2.pdf.

[11] "Open ZR+ MSA technical specification." https://openzrplus.org/.

[12] W. Shieh, X. Yi, Y. Ma, and Q. Yang, "Coherent optical OFDM: has its time come?," *Journal of Optical Networking*, vol. 7, no. 3, pp. 234–255, 2008.

[13] N. Sambo, P. Castoldi, A. D'Errico, E. Riccardi, A. Pagano, M. S. Moreolo, J. M. Fabrega, D. Rafique, A. Napoli, S. Frigerio, *et al.*, "Next generation sliceable bandwidth variable transponders," *IEEE Communications Magazine*, vol. 53, no. 2, pp. 163–171, 2015.

[14] Y. Zhang, M. O'Sullivan, and R. Hui, "Digital subcarrier multiplexing for flexible spectral allocation in optical transport network," *Optics Express*, vol. 19, no. 22, pp. 21880–21889, 2011.

[15] M. Qiu, Q. Zhuge, M. Chagnon, Y. Gao, X. Xu, M. Morsy-Osman, and D. V. Plant, "Digital subcarrier multiplexing for fiber nonlinearity mitigation in coherent optical communication systems," *Optics Express*, vol. 22, no. 15, pp. 18770–18777, 2014.

[16] H. Sun, M. Torbatian, M. Karimi, R. Maher, S. Thomson, M. Tehrani, Y. Gao, A. Kumpera, G. Soliman, A. Kakkar, *et al.*, "800G DSP ASIC design using probabilistic shaping and digital sub-carrier multiplexing," *Journal of Lightwave Technology*, vol. 38, no. 17, pp. 4744–4756, 2020.

[17] "How much carbon dioxide is produced per kilowatthour of U.S. electricity generation? [checked on Oct, 14th 2022]." https://www.eia.gov/tools/faqs/.