Digital Subcarriers: A Universal Technology for Next Generation Optical Networks

Dave Welch[(1)], Antonio Napoli[(2)], Johan Bäck[(3)], Norman Swenson[(1)], Warren Sande[(1)], João Pedro[(4)], Fady Masoud[(5)], Aaron Chase[(1)], Chris Fludger[(6)], Han Sun[(5)], Ting-Kuang Chiang[(1)], Atul Mathur[(1)], Kuang-Tsan Wu[(5)]

[(1)]Infinera, USA; [(2)]Infinera, UK; [(3)]Infinera, Sweden; [(4)]Infinera, Portugal; [(5)]Infinera, Canada; [(6)]Infinera, Germany;

dwelch@infinera.com; anapoli@infinera.com;

Abstract: Coherent technology can be operated with independent digital subcarriers to realize point-to-point and point-to-multipoint optical networks. Enabled by configurable software management, it creates a simple, scalable, low-cost solution, compatible across network, vendors, and generations.

1. Introduction

The optical network continues to evolve with the advent of edge compute, Internet of Things, deep fiber and 5G architectures [1], [2]. These advances bring not only an ever-increasing demand for bandwidth [3] but will also require that the network become simpler, scalable, lower cost, easier to operate and, in a nutshell, more flexible. The aforementioned applications will require efficient devices, such as smart transceivers, that can be remotely managed, enabling network scaling and reconfigurability to meet current and future bandwidth requirements, while minimizing the equipment needed and the operational complexity of deploying new devices on the network [4], [5]. In this paper we will discuss how an architecture based on digital subcarriers can meet the needs of the changing network, both in point-to-multipoint (P2MP) and point-to-point (P2P) applications. This can evolve to a universal technology, offering compatibility not only between vendors but also between different generations of network equipment.

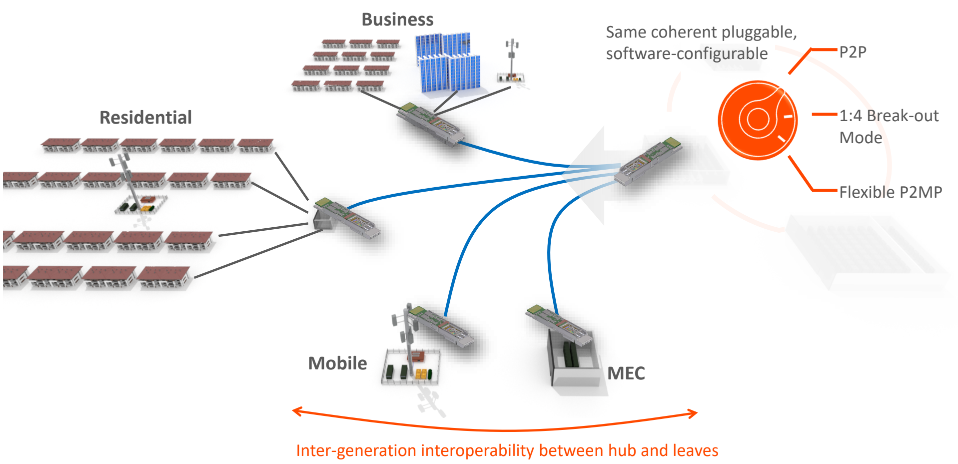

Fig. 1: P2MP network enabled by digital subcarrier multiplexing. MEC: multi-access edge computing.

2. Digital Subcarrier Multiplexing

Digital subcarrier multiplexing slices a wavelength into multiple subchannels that can be addressed to different end nodes in a P2MP architecture as illustrated in Fig. 1. The underlying technology is implemented by an optical transmitter and receiver optical sub-assembly (TROSA) and a digital signal processor (DSP). The TROSA modulates and demodulates two complex baseband electrical signals to and from the two polarizations of an optical carrier. The DSP generates, modulates, and receives the digital subcarriers that comprise the electrical complex baseband signals [6]. The DSP also compensates for fiber and component impairments (e.g., dispersion compensation) and performs time and frequency synchronization. The digital subcarriers determine dedicated frequency channels for particular applications and potentially specific end users and end-user locations. They can be transmitted over different distances to enable P2MP transmission. In this configuration, the DSP will become a system on a chip (SoC) that manages the overall integration of the various optical elements. All of this is implemented within a pluggable optical transceiver that can be integrated into various host platforms. There are several unique architectural benefits of a system based on digital subcarrier multiplexing:

1. Digital subcarriers support both P2MP and P2P applications. In a P2MP application, digital subcarrier multiplexing facilitates savings by eliminating intermediate aggregation routers/switches and associated transceivers that are otherwise required to multiplex P2P links, as described in [4]. In a P2P application, digital subcarriers do not compromise the reach of the transceiver, rather they enable optimized network utilization by selectively adapting/loading those parts of the spectrum that can transmit more capacity or are subjected to strong filter penalties [7], [8]. Both applications benefit from advanced remote diagnostic tools enabled by the fine-grained subcarriers. Moreover, the use of a common technology for both applications creates overall network simplification.

2. P2MP architectures are derived by locking the clock and optical frequency of the hub and edge elements. This facilitates a spectrally dense broadcast network architecture, highly advantageous for access networks to enable low-cost implementation and reconfigurable bandwidth on demand. Furthermore, these coherent solutions are fully compatible with existing and future passive optical network (PON) architectures. Fig. 2 shows an example of a P2MP architecture based on digital subcarrier multiplexing realized as a PON overlay.

3. Inherent in the subcarrier architecture is the ability to remotely reconfigure the bandwidth allocated to a particular edge device. With subcarriers capable of 25 Gb/s in a 4 GHz spectral slice, the network can allocate a multiple of 25 Gb/s subcarriers to a particular application and that bandwidth can be reconfigured without having to change the remote elements.

4. With a common subcarrier implementation between the edge and hub elements, as the bandwidth is increased through a multiple of 25 Gb/s subcarriers, the cross generational compatibility is intrinsically ensured. This enables 25 Gb/s transceivers to "talk" with 100 Gb/s transceivers as well as 400 Gb/s, 800 Gb/s, or even 1600 Gb/s ones, with no compromise to reach or performance of any particular generation.

5. The P2MP architecture as applied to aggregation networks further diminishes the dependency on switches and routers and in addition, reduces the number of optical elements, resulting in cost reductions ranging from 30% up to 70% [4], [9], as reported in Fig. 3(a) (further discussed below). This enhances network reliability and simplifies operation and upgrades.

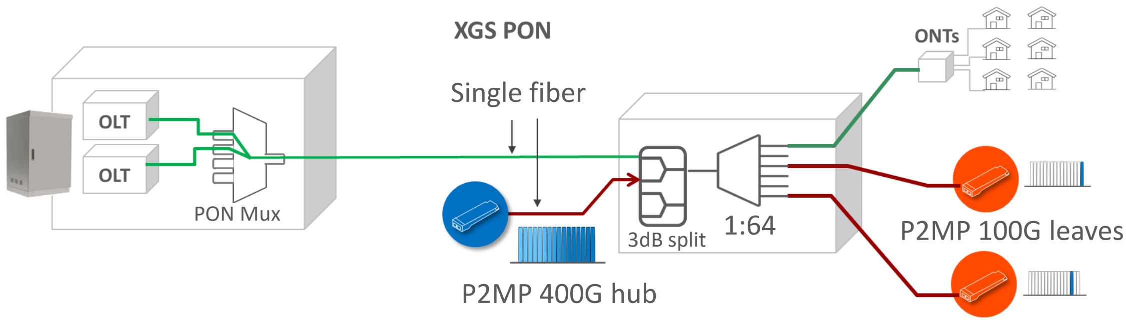

Fig. 2: Digital subcarrier overlay of existing PON Network.

By adopting a common specification based on multiple subcarriers, the end user will achieve the lowest cost network architecture, with generational compatibility, and ease of scale. A common interface from edge to core devices will also create the lowest cost manufacturing infrastructure and a defined standard for integration into a diversity of host platforms. The greatest value of this compatibility is the reduction of cost in the network and the uniformity of the specification across all optical network applications. To evaluate the benefits of a P2MP architecture, a series of metro networks were investigated. Fig. 3(b) shows the topologies, i.e., 226 dual-hubbed horseshoes, considered in [9]. This was part of a nationwide service provider network with traffic from 1000 central offices feeding into 100 core sites. We evaluated up to 9 central offices per link, and 4-5 fiber degrees per core site. The minimum distance was 2 km, the maximum 284 km. We considered a hub and spoke traffic pattern, and a compound annual growth rate (CAGR) level of 30% over five years. This analysis led to the results set out in Fig. 3(a), where we report the normalized cumulative CAPEX for four solutions: 100G/200G/400G with P2P, and P2MP (in yellow). The savings achieved by the P2MP versus legacy coherent P2P solutions was ∼70%. It was also shown that employing P2MP transceivers results in net savings if their premium cost is not higher than 50% of the equivalent traditional P2P transceiver in [10].

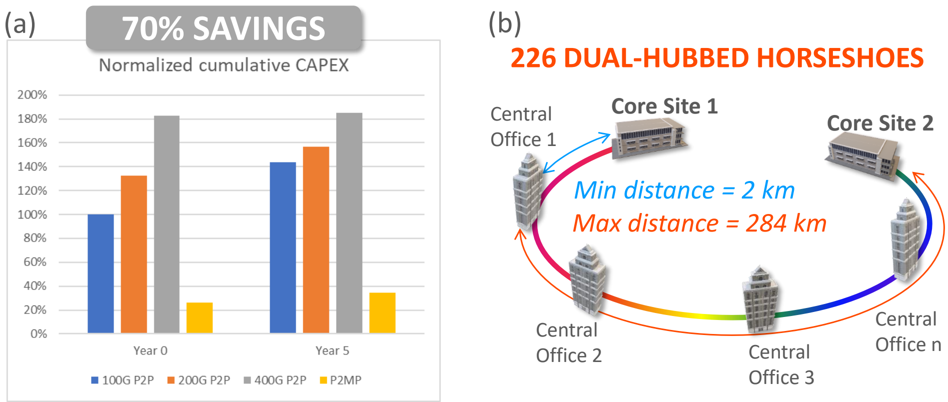

Fig. 3: (a) Results of cost analysis; (b) Horseshoe dual-hubbed topology for cost study.

3. Conclusion

Advanced coherent optics, architected to operate with independent digital subcarriers, can meet the needs of both point-to-point and point-to-multipoint applications without compromises in performance. The software-configurable management of the point-to-multipoint architecture enables a simple, scalable, low cost and easy-to-operate network that can create compatibility between vendors and across multiple generations of transceivers. With digital subcarriers, we can adopt a single solution set across the network, improving cost efficiency, and simplifying network operation and upgrades.

References

[1] A. Rashidinejad *et al.*, "Real-time demonstration of 2.4 Tbps (200Gbps/) bidirectional coherent DWDM-PON enabled by coherent Nyquist subcarriers," in *Optical Fiber Communication Conference*, Optical Society of America, 2020, W2A–30.

[2] J. S. Wey and J. Zhang, "Passive optical networks for 5G transport: Technology and standards," *Journal of Lightwave Technology*, vol. 37, no. 12, pp. 2830–2837, 2018.

[3] *Cisco Annual Internet Report (2018–2023) White Paper*, Cisco Annual Internet Report (2018–2023) White Paper.

[4] D. Welch *et al.*, "Point-to-multipoint optical networks using coherent digital subcarriers," *Journal of Lightwave Technology*, vol. 39, no. 16, pp. 5232–5247, 2021.

[5] A. Napoli *et al.*, "Live network demonstration of point-to-multipoint coherent transmission for 5G mobile transport over existing fiber plant," in *European Conference on Optical Communications (ECOC)*, IEEE, 2021, pp. 1–4.

[6] H. Sun *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.

[7] D. Che and W. Shieh, "Adaptive multicarrier modulation for flexible optical networks," in *2018 23rd Opto-Electronics and Communications Conference (OECC)*, IEEE, 2018, pp. 1–2.

[8] T. Rahman, D. Rafique, B. Spinnler, *et al.*, "Digital subcarrier multiplexed hybrid qam for data-rate flexibility and roadm filtering tolerance," in *Optical Fiber Communication Conference*, Optical Society of America, 2016, Tu3K–5.

[9] J. Bäck *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)*, IEEE, 2020, pp. 1–4.

[10] N. Skorin-Kapov, F. J. M. Muro, M.-V. B. Delgado, and P. P. Marino, "Point-to-multipoint coherent optics for rethinking the optical transport: Case study in 5G optical metro networks," in *2021 International Conference on Optical Network Design and Modeling (ONDM)*, IEEE, 2021, pp. 1–4.