Disruption Cycles for Optical Networks: How Point to Multi-Point Coherent Optics can Transform the Cost and Complexity of the Optical Network

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Abstract *XR Optics is a family of point to multi-point transceivers that can interoperated across a variety of different speed transceivers. By employing individually routable digitally generated sub-carriers we demonstrate for the first time the dramatic cost savings and simplification of the fiber optic network.*

Optical networks have gone through several technological disruption cycles over the past several decades. Each disruption has resulted in a dramatic re-architecting of the network to accommodate a dramatic reduction in the cost and complexity of the network. The introduction of erbium doped fiber amplifiers (EDFAs) resulted in the movement from repeatered networks to amplified networks. The introduction of dense wavelength division multiplexing (DWDM) technologies offered the ability to substantially increase the scale and capacity of the fiber infrastructure. The introduction of photonic integration addressed both capacity per unit and overall cost structures. Reconfigurable optical add-drop multiplexers (ROADMs) created even more flexibility and efficiency in the network. More recently, coherent transceivers, which were introduced in 2010, have driven cost per bit down and fiber capacity up. All of these advancements were enablers for the restructuring of the optical network and have been fully embraced by the industry; it has been repeatedly demonstarted that the major advances to network cost structure have arisen from the adoption of innovative advanced technologies.

Since its announcement at ECOC 2019 and in recent publications, another technology with the potential for disruptive change to the economics and simplification of the fiber optic network was introduced: the demonstration of XR optics, coherent transceivers that are capable of operating in a point to multi-point (P2MP) configuration[1]-[2]. XR technologies are a paradigm shift from existing high capacity optical transceivers, where the connectivity is such that a single transceiver, operating at a hub location, is not restricted to a communication to a single end point, but can simultaneously and continuously talk with many lower speed transceivers across the network. This paradigm change greatly impacts the overall cost structure of aggregation networks as it replaces the traditional electronic aggregation technologies in the form of Layer 1 and Layer 2 muxponders with a simple optical muxing element.

Figure 1 presents the transition from a traditional network architecture, where low speed transceivers closer to the optical edge operate over a series of optical links, to a Layer 1 or Layer 2 muxponder. In this case, there are 2N transceivers for N optical links as all transceivers in this paradigm can only connect to similar speed transceivers. Further, the electronic muxing that is required to aggregate this traffic to a higher speed transceiver requires space, power and significant cost. Also presented in Figure 1 is the paradigm where the low speed transceivers are able to communicate directly to a high speed transceiver. In this paradigm, the number of transceivers required for N optical links is not 2N but instead is N+1, reducing the number of required transceivers by ~50%. In this paradigm, the low speed transceivers are locked in frequency in a main/executor relationship to the high speed transceiver and consequently they do not require a muxponder to aggregate the signals from the low speed transceivers. The net economic benefit when considering the 2x reduction in transceivers and the elimination of aggregation layers can be as high as 70% of the current network cost structure.

Figure 2 represents the way in which, through the use of design modifications within the DSP of the coherent transceiver, the normal single band of information that results from the modulation of information on the the optical carrier can be designed to accommodate a number of frequency channels. Although these frequency channels can be arbitrary, here we will limit the discussion to the scenario of uniform frequency channels.

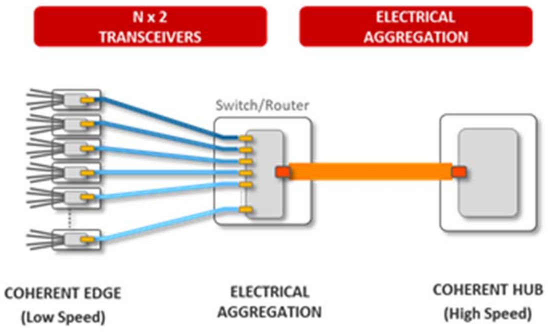

Fig. 1: Comparing the configuration of a traditional point to point optical network (a) with that of a XR point to multi point network(b).

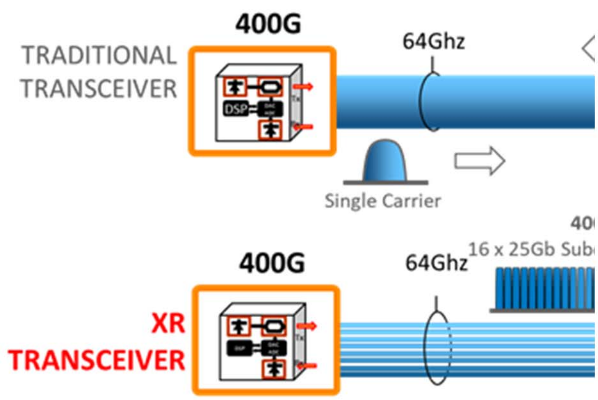

Fig. 2: The concepts of digitally generated frequency channels from the same optical sources, however a different configuration of the DSP.

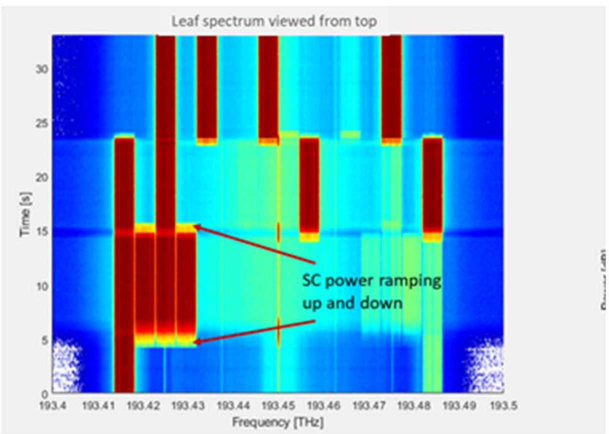

Fig. 3: Demonstrating the ability to turn on/off theconfiguration of sub carriers as a function of time. At time of t=0 we start transmitting 25 Gb in a single frequency channel followed by a redefinition of the loading of the frequency channels as defined by the management plane.

The output of a P2MP coherent transceiver is a number of discrete sub-carriers or frequency channels that have been framed and error-corrected independently from each other, allowing each digitally generated subcarrier to be associated with a different element in the network. In this fashion, the coherent transceiver has become a P2MP transceiver and can realize the economic and simplification benefits that we have described above.

We have demonstrated the P2MP technologies in a variety of deployed network topologies, ranging from single and dual fiber topologies to aggregation networks that include PON infrastructure, and ROADM networks with protection ring configurations. As a result of the inherent flexibility in the definition and allocation of frequency channels, XR optics is compatible with most as-deployed network architectures. For full flexibility and lowest cost implementation, XR optics is deployed in a broadcast configuration as it pertains to the capacity that is aggregated by the individual hub optic. The broadcast capability results in the presentation of the full capacity signal being presented at each leaf element, however, through the management plane, the leaf elements are assigned particular subcarriers. The assignment and the potential re-allocation of frequency channels or subcarriers is done remotely through the management plane, and enables a simple provisioning of traffic to meet any traffic demands over the life of the element. Figure 3 shows the spectrum of a 400 Gb 16 channel tranceiver being operated in various modes, where the output is varied over time from 25 Gb to 100 Gb, and where the subcarriers allocated to the 100 Gb mode of operation are varied across a different set of subcarriers or frequency channels as a function of time. In this fashion the bandwidth can be allocated and reconfigured on demand, enabling a reallocation of bandwidth remotely without the need of truck rolls for service modifications.

Finally, by establishing the communication connectivity between low speed interfaces and high speed aggregation elements, the upgrade of the network can be dramatically simplified. In standard point-to-point optical networks, any upgrade at one element of the network that is on a link or ring, requires that all other locations also be upgraded so that the transceivers can continue to talk to each other as the transceiver speed is increased. For instance, if we have a ring that uses 100 Gb optics, and we want to upgrade that to 400 Gb connectivitiy with 400 Gb transceivers, we are required to upgrade all elements along that ring, a process that usually requires an upgrade to each box, whether a switch, router or transport box. In the XR paradigm where the low speed transceivers can talk directly to the high speed transceiver, when you want to increase the capacity at one element in the fiber ring, it is only necessary to upgrade that one location. This feature greatly reduces the cost and complexity of upgrading the network elements.

In this talk, we will discuss the technical accomplishments to date and the demonstrations of the XR technologies in real networks and the implications of the paradigm change for the networks of the future.

[1] A. Rashidinejad, A. Nguyen, M. Olson, S. Hand and D. Welch, "Real-Time Demonstration of 2.4Tbps (200Gbps/λ) Bidirectional Coherent DWDM-PON Enabled by Coherent Nyquist Subcarriers," *2020 Optical Fiber Communications Conference and Exhibition (OFC)*, San Diego, CA, USA, 2020, pp. 1-3.

[2] C. Fludger, "Performance Orientated DSP design for Flexible Coherent Transmission," in *Optical Fiber Communication Conference (OFC) 2020*, OSA Technical Digest (Optical Society of America, 2020), paper Th3E.1.