Coherent Optics for Access from P2P to P2MP

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Abstract: Coherent optics is being re-designed to future-proof access networks using P2P and P2MP systems. Coherent optics' higher speeds and link budgets, provide significant deployment flexibility. Coherent optics architecture, standards, and service implications benefits are discussed.

1. Introduction

The insatiable appetite for higher and higher capacities in the access have been addressed by cable, DSL, wireless, passive optical network (PON) and point-to-point (P2P) Ethernet technologies through progressively increasing data rates to meet this growing traffic demand. Nevertheless, the backhauling needs of these networks' traffic, the demand for connectivity to much higher number of end-devices, and the need for efficient use of existing fiber infrastructure and operational scalability prompts a more significant improvement in optical access transport. Coherent optics has been used widely in the backbone and subsea supporting interconnectivity among major hubs and for aggregation of larger amounts of traffic. Meanwhile the access network environment is evolving to require higher capacity, lower latency, and greater resiliency. We contend that coherent transport is the natural long-term access evolution strategy to address these changes [1].

2. Access fiber topology

To better assess the access environment, we need to look first at its topology and how fiber connectivity has been evolving. In the past, the access fiber deployments have focused on connectivity to intermediate points that represent capacity aggregation or backhauling points. These could be connectivity to remote DSLAMs, wireless eNodeBs/gNodeBs, remote cable modem termination systems (CMTSs), remote optical line terminals (OLTs) etc. Typically, fiber strands and/or wavelengths were dedicated from a central office or hub to these aggregation devices.

More recently as fiber connectivity penetrates deeper, the original endpoints become distribution points connecting to a larger number of newer endpoints. This direct connectivity to end-users, could be enterprise connectivity or even fiber-to-the-home (FTTH). As fiber is deployed deeper towards the customers, some of the original broadband transport such as coax, twisted pair or wireless, transitions to optical transport where a much larger number of fiber strands connects to smaller broadband serving areas resulting in a fiber count mismatch at this new distribution point. Maintaining fiber-to-fiber mapping after initial build-out, is not cost advantageous. Sharing connectivity through optical splitting, tapping, or connecting to optical carriers leveraging wavelength manipulation become important tools in access connectivity. Based on these fiber access topology scenarios, traffic characteristics and service requirements, network planners need to decide whether P2P or point-to-multi-point (P2MP) connectivity is more advantageous.

3. Coherent optics re-design for access networks

Coherent technology has been used extensively in long-haul and backbone environments addressing connectivity needs with technology offering highest speed or spectral efficiency along with longest distance transport. Some backbone links, as long as 3000 km, traverse numerous amplification stages. In these types of optical links, efficient error correction was introduced along with significant dispersion compensation leveraging extensive digital signal processing (DSP). In the access environment, distances are more like 30 km rather than 3000 km. In many cases, access distances can be covered through only one booster or pre-amplifier or even un-amplified optical links, limiting the noise and distortion introduced by optical amplifiers, fiber nonlinearity, and the number of ROADMs and multiplexer filters in cascade are reduced, alleviating distortion compensation needs as well. Distance related impairments such as chromatic dispersion and polarization mode dispersion require much lower amount of DSP resources.

In contrast to intensity-modulation direct-detection (IM-DD), the coherent receiver uses a local oscillator as additional coherent gain, resulting in much greater receive sensitivity and a much larger link budget (LB). It is this link budget, that can be used to relax implementation requirements, providing generous capacity and an enviable link length compared to what the access environment has typically enjoyed through IM-DD. While IM-DD systems achieve sensitivities around -25 dBm for 25G and -30 dBm for 10G [2], coherent systems achieve at 100G a sensitivity gain of 10 dB compared to IM-DD [3]. Coherent systems traditionally have come at greater cost, but through access specific re-design, significant simplification and cost/power reduction can be achieved.

In cable, about 90% of the hub to fiber-node link lengths are less than 40 km [4]. In the telco environment, these distances are even shorter due to the higher density of central offices compared to cable hubs. Almost all access link lengths are encompassed within 80 km. Based on access distances and current and future traffic aggregation and distribution needs, predominant use-case scenarios can be addressed by 100G and 200G systems.

While early on in access, the traffic was heavily residential, the amount of enterprise traffic and wireless backhaul traffic have been steadily increasing. These and other drivers lead to an evolving traffic mix. While the number of services and applications in the access has been increasing, still a significant portion of the traffic is video related. A growing portion of these applications require lower latencies while having greater reliability has become intrinsically tied to a better quality of experience.

P2P links can be used to backhaul large amounts of data aggregated from remote DSL access concentrators, remote CMTSs, base stations and enterprise traffic, which themselves aggregate traffic from many end-stations. In general, aggregate traffic by its statistical multiplexing nature, presents a continuous and slowly varying traffic load. In P2MP deployments, traffic requirements could be somewhat different. While in principle P2MP could also be aggregating traffic from smaller networks, the fact that P2MP is typically connecting to deeper points in the network, smaller serving areas with fewer number of endpoints are backhauled and even connectivity to a single endpoint is established (i.e., FTTH). In this scenario, the variability in time could be better addressed by protocol based dynamic bandwidth allocation of a TDM/TDMA PON system. Even if there is constant traffic flow, having greater control in granularity of the amount of allocated bandwidth, leads to a more efficient use of resources. The selection of a P2P or a P2MP will depend on factors such as use case, traffic type, available resources, and topology. In both P2P and P2MP cases, coherent optics enhances their performance metrics. Especially in P2MP topology, with the increase of coherent PON (CPON) ability in higher capacity, longer reach, and higher split ratio, its applications are now extended to support many more optical connections, such as the new radio access network for the high-capacity x-haul transport of 5G and beyond 5G mobile networks, enterprise and business, access aggregation architecture, even to data centers' aggregated connections. All these present new opportunities as well as challenges of a single platform for convergence of broadband wired and wireless access networks.

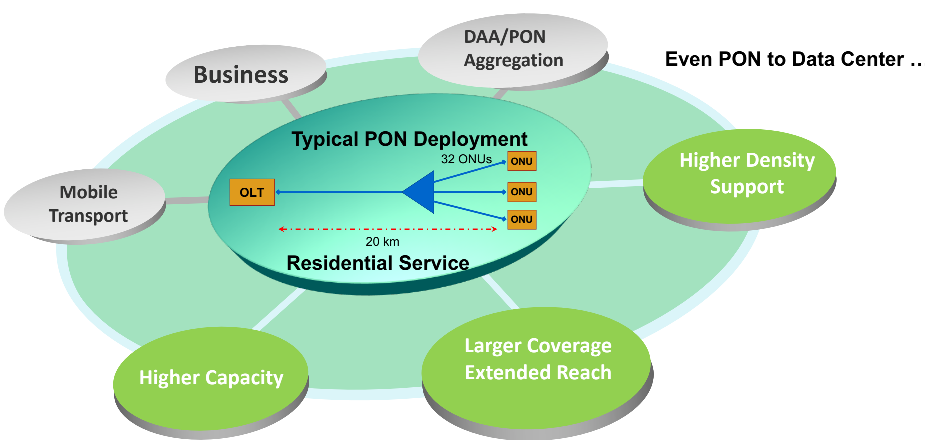

Figure 1 – Extended CPON applications

4. Technology optimizations of Coherent Optics for access networks

Certainly, the coherent receiver requires a local oscillator which provides coherent gain and the resulting link margin advantage. It comes, however, at the expense of an additional higher quality local oscillator laser and a more elaborate receiver architecture. There are certain approaches that can be leveraged to simplify coherent transport taking advantage of the access environment conditions.

DSP simplification due to the much shorter access distances is an obvious approach. At symbol rates of about 25 GBd, chromatic dispersion can be compensated for links < 80 km using around 20 taps compared to over 500 taps in coherent links greater than 1000 kms [5]. In fact, when approaching this number of taps one can incorporate chromatic dispersion compensation within the butterfly equalizer structure such as the ones used with constant modulus algorithm (CMA) without requiring a separate chromatic dispersion block. Since for access link lengths, the number of filtering components traversed such as multiplexers and demultiplexers are reduced, the fiber nonlinearity is not major challenge anymore, equalization complexity is also reduced, enabling a fast convergence. In shorter links, amplification stages are limited or non-existent thereby also reducing the added noise in the link. Optimal 100/200 Gbps access link rates result in coherent systems with symbol rates of 25 GBd or higher, easily fitting in conventional 50-GHz ITU grid. These baud rates and the use of quadrature phase shift keying (QPSK) modulation format make the system more resilient to the impact of wider linewidths and corresponding phase noise. Lower cost DFB/DBR lasers, with linewidths of higher than 1 MHz, have been introduced in coherent systems with minimal impact in performance [6]. Optical injection locking has also been proposed, where a higher quality parent laser injection locks multiple child FP lasers generating a high-quality narrow linewidth signal with low-cost FP lasers [7]. Quantum dot lasers are also promising as a low-cost alternative of simultaneous multiple optical signal generation [8]. Another simplification that can be leveraged when implementing 100 Gbps access links with the use of QPSK modulation is on nested I/Q modulation. It could be implemented with a single phase-modulator, trading modulator driver signal complexity with a lower optical loss present in nested IQ modulators.

In the access environment there is an inherent advantage of cable hubs and central offices' hub-and-spoke fiber topologies. Generation of multiple signals out of a common distribution point enables replication mechanisms like the parent-child optical injection locking system or generating multiple wavelengths out of a common source such as what can be done leveraging optical frequency comb sources with fan-out of wavelengths into fibers through wavelength demultiplexing into separate paths. In the access, 100G and 200G will handle suitable aggregate rates for quite some time, with only few cases where a single end-subscriber may require bursting up to 100 Gbps. To take advantage of this subscriber behavior, segmentation of the downstream and upstream into digitized subchannels can provide some advantages. Some implementations of digitized coherent subchannels are being developed by the XR Forum MSA and others [9,10] and can be applied in CPON implementations. A division of 100G channel into 4 digitized 25 G sub channels result in a 6 dB link budget improvement. That can be leveraged to increase link length, split ratio or speed. It can be used to provide redundancy at lower rate but a longer secondary path. A TDMA uplink provides the granularity of service needed for the large and diverse number of CPON subscribers with a better flexibility and bandwidth utilization, for which efficient burst detection mechanisms have been demonstrated [3].

5. Conclusion

Introduction of coherent optics transport of 100G and 200G rates in the access using P2P and P2MP systems has been reviewed. Opportunity for extended use cases and to reduce complexity and cost at the receiver, laser source, modulator and by leveraging hub-and-spoke access topologies have been discussed. Coherent optics' ample link budget enables many complexity-reduction approaches. While 100G may appear an overkill for most end-subscribers today, it is very appropriate for backhauling aggregate traffic. Traffic type and how deep fiber is deployed play a significant role as to whether P2P or P2MP solutions are better suited for a particular use case. The deployment flexibility of CPON along with its associated capacity can lead to a potentially extremely long service lifespan. CPON operational aspects, long term use of technology, cost per bit, traffic demand, deployment flexibility, end-to-end network simplification, play a bigger role in evolving to CPON from IM-DD PONs than just reaching 100G. Access specific re-design of coherent optics silicon becomes a catalyst of this evolution path.

6. References

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