Will a metro-access optical continuum ever fly? deployment challenges and enabling technologies

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Abstract: We discuss optical continuum techniques to cut the total cost of ownership of telecom operators optical networks, and review enabling photonic technologies, particularly focusing on recent advances of silicon photonics-based reconfigurable optical add drop multiplexers.

1. Introduction

In all practical network deployments, information data travelling from the access segment to the metro segment, and beyond, undergo several aggregation stages, to benefit from the advantages of statistical multiplexing in network resources utilization. However, this comes at a price of higher energy consumption, number of sites and operation complexity; in short, higher Total Cost of Ownership (TCO). Past proposals to save packet aggregation stages, bypassing them with transparent optical links, never flew, due to issues in (dynamically) provisioning large amounts of aggregated traffic at an affordable cost. Recent advances in integrated photonics may change the situation, reducing footprint, power consumption and cost of the Reconfigurable Add Drop Multiplexers (ROADMs) needed to implement network architectures based on optical continuum. Examples of these architectures will be discussed in Section 2. In Section 3, we will introduce enabling photonic technologies.

2. Use cases and scenarios for optical continuum in metro and access networks

Telecom operators typically organize their optical networks by domains (e.g., access, metro, regional, and backbone). Equipment is placed at each boundary to manage the domains interconnection, handling the different control and data plane requirements and accordingly aggregating and distributing traffic. These demarcation points allow to clearly divide the responsibility of the different company organizations in specialized sectors. However, if this functional segregation helps to manage the high complexity of the optical network, it also has drawbacks: low flexibility, complex end-to-end service delivery and management, bulky and energy consuming equipment, and high number of sites. As a matter of fact, today operators are struggling with the TCO of their networks. One intuitive way to lower the TCO would be centralizing the network functions, avoiding as much as possible intermediate processing (and equipment) by means of transparent optical links. This holds especially for the access and metro segments, where the TCO can easily explode due to the large number of end-users to connect. In access, the (still ongoing) replacement of legacy copper solutions (xDSL) with Passive Optical Networks (PONs) has greatly reduced the maintenance cost, while increasing the overall performance. One of the reasons is that PONs only require power at the Optical Network Termination (ONT) and the Optical Line Terminal (OLT) ends. However, the maximum covered distance in a PON is 20 km [0], making it necessary to host the OLT at a Local Central Office (LCO). Operators would further benefit from longer distances to optically bypass the LCO, moving power-hungry packet processing far towards the regional domain, or beyond. This is advantageous for typical fixed-access and 4G x-haul scenarios, but 5G and Edge Cloud are introducing new use cases that require low-latency and high bandwidth, for low-layer split fronthaul or Ultra-Reliable Low Latency (URLL) services. These services may still need LCOs for hosting mini datacenters performing a minimal amount of computing, networking and storage tasks. Given that installing and maintaining an access infrastructure requires a huge investment, it takes several decades to become profitable. This makes it mandatory for operators to introduce flexible solutions to accommodate services that may have very different requirements and evolve in time. Wavelength Division Multiplexing (WDM) overlay over PON is one of these solutions, allowing operators to assign different optical bands to different kinds of services sharing same fiber and passive infrastructure. Several fixed access systems exploit WDM [2] in combination or in alternative to Time Division Multiplexing (TDM) (Figure 1.a). Such a way, it is possible to assign dedicated band channels to low-latency services avoiding the TDM scheduler. Using ROADMs, it is also possible to dynamically select which bands should by-pass a site or be packet-processed locally (Figure 1.b).

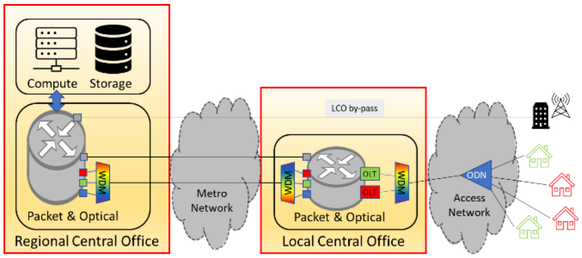

Figure 1.a: WDM overlay on passive infrastructure

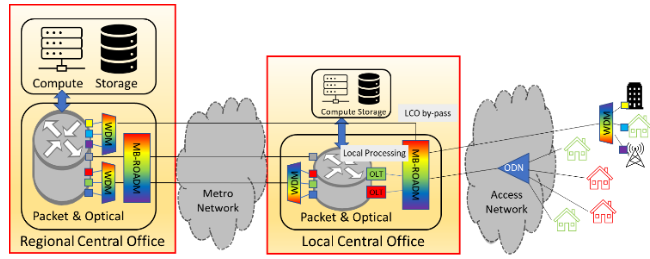

Figure 1.b: Flexible band assignment with Multi Band (MB) ROADMs

This approach enables flexible network scenarios where traffic coming from different users and directed to the same core destination is packet-processed for grooming at intermediate local or regional sites until a specific threshold is reached. Once the threshold is exceeded, a direct optical bypass towards the destination is implemented by means of ROADMs located at intermediate nodes [3]. Similar use cases for optical bypassing are considered in more complex architectures [4], based on ROADMs and Sliceable Bandwidth Variable Transponders (S-BVT). One of the use cases in [4] takes advantage of the fact that most of the traffic in a Metropolitan Area Network (MAN) is hierarchical (i.e., uplink aggregation and downlink distribution). In the proposed architecture, traffic is packet aggregated in local access routers and sent to the top-level routers of a national backbone, bypassing an aggregation layer consisting of intermediate regional routers. The authors report 40% cost savings combining this approach with a network planning strategy that exploits the bandwidth flexibility of multi-terabit/s S-BVT having 50 Gbit/s wavelength granularity. The reason lies in the significant reduction of the regional routers that handle the low residual amount of traffic between different local access domains. In the same paper, similar cost saving figures are claimed, based on the same technologies, for ultra-low latency point-to-point services that in absence of optical switches would need dedicated fibers. In future, Multi Band (MB) optical switches may expand the available capacity of optical fiber systems, up to around 53 THz [5], enabling non-hierarchical architectures where edge access nodes are all-optically interconnected with top-hierarchical nodes, interfacing Content Delivery Networks (CDN) [6].

3. Enabling technologies

The ROADM is the key optical subsystem in all the scenarios illustrated in the previous section. Characteristics, definitions and transfer parameters of multi-degree ROADMs are explained in [7], together with examples of node configurations. The Open ROADM Multi-Source Agreement (MSA) [8] defines interoperability specifications for ROADMs, transponders and pluggable optics. Its purpose is overcoming the drawbacks of the current proprietary implementations, simplifying the system integration and testing processes and shortening the technology lifecycle of the ROADMs in the network. Another goal is eliminating any fixed internal connections and pre-defined wavelength ports or directions, making the system remotely configurable. This approach uses disaggregated hardware and open interfaces to save operational costs. A parallel technology trend to reduce the TCO relies on silicon photonics to realize ROADMs as systems-on-chip (SOC), reducing footprint, power consumption and cost. These integrated designs replace the essential but expensive component of a ROADM, the Wavelength Selective Switch (WSS), with much cheaper photonic integrated circuits (PICs). Several implementations of silicon photonics ROADMs have been reported based on ring resonators, Arrayed Waveguide Gratings (AWGs), echelle gratings or Mach Zehnder (MZ) interferometers and switches. The example in [9] uses sidewall-corrugated contra-directional couplers and MZ switches to achieve high extinction ratio and large free-spectral range (FSR). In [10], a space-and-wavelength selective switch fabrics, based on Micro-Ring Resonators (MRR), selects the channels, with larger ring elements used as comb aggregators to block the first-order crosstalk. This design avoids grating structures, reducing the design complexity, and allows arbitrary combinations of wavelengths. The insertion loss at the interface between silicon waveguide and optical fiber (a couple of dBs in the best implementations) is a general issue of silicon PICs. Silicon integration with III-V materials, to include Semiconductor Optical Amplifiers (SOAs) in the same PIC, is often proposed as a solution to realize so called lossless devices. In addition, both silicon PICs and SOAs can work in O band. This makes it possible to upgrade fixed access networks applying optical continuum techniques to enable more flexibility (Figure 1.b). However, using SOAs as line amplifiers leads to performance penalties in WDM systems, due to their non-linearity [11]. Erbium Doped Waveguide Amplifiers (EDWA) avoid these issues, but technology is less mature and attainable gain is lower. Lossless Silicon Nitride ROADMs based on MZ interleavers with monolithically integrated spiral EDWAs were demonstrated in the C band [12]. The achievable performance in the O band, using alternative doping elements, such as Praseodymium and Bismuth, is a matter of future research. In general, reducing at the same time hardware costs, by means of highly integrated and specialized designs, and operational costs, following a hardware disaggregation approach, is still an open challenge. Looking at the future, novel architecture leveraging on both Spatial Division Multiplexing (SDM) and WDM can prevent bottlenecks in spectral efficiency when moving to 10 Tbit/s optical line interfaces [13]. They may be based on spatial cross connects with single mode standard fibers or multi-core fibers [13,14] or on multi-granular optical nodes architectures and waveband-selective switches [5]. However, these technologies are only applicable to new deployments, which contradicts the evolutionary network upgrade approach that most operators adopt for ensuring sustainable profits. ROADMs are not the only enabling technology for optical bypassing. Although probably not cost effective for the access segment today, coherent sub-band technologies [15] could allow, in high bit rate systems, to dynamically bypass lower bit rate traffic or local processing requests over short distances. Finally, it is worth to note that, although the focus of this section was on optical technologies, optical continuum-based architectures also need proper control strategies, not addressed here, to manage end-to-end services from the access to the core.

4. Conclusions

New implementations of ROADMs as photonic SOC enable optical network architectures based on optical continuum to downsize the equipment and simplify the network operation, so meeting operators' request for TCO reduction. Silicon photonics is the most promising photonic integration technology, offering a wide library of fundamental components (optical switches, wavelength demultiplexers, optical modulators, wavelength switches, etc.). The programmability of these new designs is the key to manage different kinds of services that may need or not local packet processing. However, there are still challenges to be faced. The realization of lossless WDM devices with acceptable performance is an example of technological challenge. Even more important, standardized fabrication processes, digital design tools and open system interfaces should be put in place for photonic integrated ROADMs, to enable global solutions producible in high volumes in an open market. Finally, the technology roadmap should move in parallel with the services evolution and not postulate unrealistic sudden renewals of the fiber infrastructures.

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