Efficient Optical Packet Transport in Access, Metro, and Core Networks

A. Autenrieth[(1)]
[(1)] *ADVA AG Optical Networking, Fraunhoferstr. 9a, 82152 Martinsried, Germany*
aautenrieth@advaoptical.com

Abstract: We present and evaluate opportunities and challenges for packet optical transport of residential and business data services from access to core networks. Presented solutions are evaluated based on sample case studies.

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1. Introduction

The continuously growing bandwidth consumption of the digital society drives operators to reduce network capital expenditures (CAPEX) and operational expenditures (OPEX). Corporate responsibility and growing energy cost furthermore increase the need for energy efficient transport networks. The Packet Optical Transport Network aims at this goal with the integration of packet switching (MPLS), TDM switching (ODU), and wavelength switching (DWDM) in a single transport network, thus coupling bandwidth management and transmission functionality.

However, several technological and architectural choices are available, and the resulting multilayer transport network has many degrees of freedom. The different technologies have each their strengths and areas of application: packet switching for aggregation and statistical multiplexing, TDM switching for efficient grooming and bandwidth management, and wavelength switching for optical bypass and energy efficient long haul transmission. This requires careful design and optimization to obtain maximum synergies with a robust and scalable architecture.

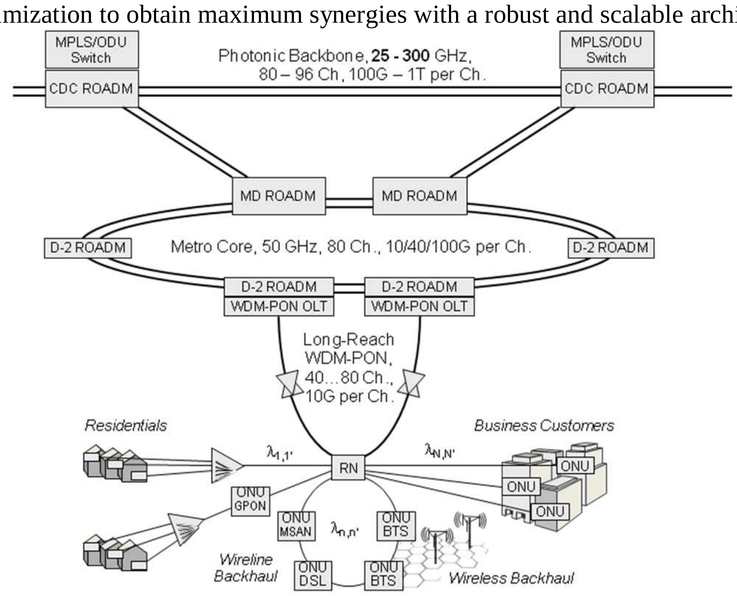

Fig. 1. Converged transport network. In the metro area, access and backhaul are based on high-capacity, long-reach WDM-PON. The Optical line terminals (OLTs) connect redundantly to high-capacity metro core rings which again are redundantly connected to a meshed photonic backbone (RN: Remote node, ONU: Optical network unit, GPON: Gigabit passive optical network, MSAN: Multi-service access node; BTS: Base transceiver station).

Figure 1 shows a reference transport network architecture based on passive optical access network using WDM-PON and GPON, a Metro Core network with degree-2 (D2) and multi-degree (MD) ROADMs, and a core network with 100Gbit/s – 1Tbit/s per channel using colorless, directionless, contentionless (CDC) ROADMs together with hybrid MPLS/ODU-Switches. In the remainder of the paper, the three network areas will be discussed in more detail.

2. Passive Optical Access Network

Next-generation access systems will have to provide bandwidths in excess of 100 Mb/s per residential customer, in conjunction with high customer count and high maximum reach. Potential systems solutions include several variants of WDM-PONs. These systems, however, differ significantly in their cost (capital expenditures) and energy-consumption potential. Several WDM-PON concepts are currently investigated in the European funded IST research projects OASE [1] and C3PO [2], as well as the project ADVAntage-PON funded by Germany's Federal Ministry of Education and Research (Bundesministerium für Bildung und Forschung, BMBF). An overview and evaluation of WDM-PON solutions including hybrid WDM-PON with integrated per-wavelength multiple access, is given in [3].

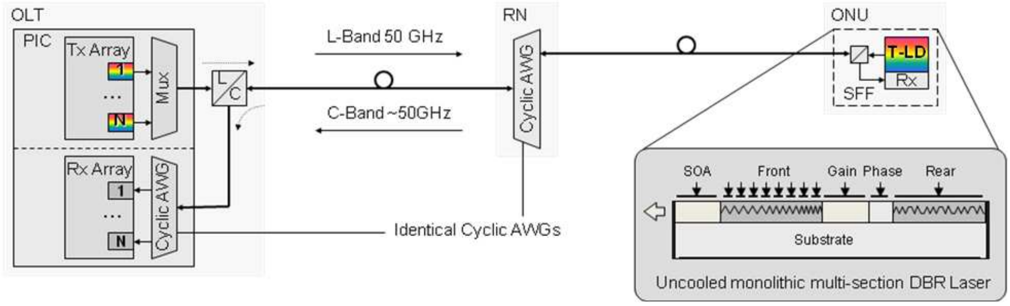

Fig. 2. Simple WDM-PON (64…96 Ch)

The author shows that a simple WDM-PON as shown in Fig. 2 is most efficient for next-generation access with up to 1 Gb/s (sustained) per client and client numbers not exceeding ~320. Access distances of 40…60 km can also be supported. This can be attributed to the inherent simplicity of the transceivers and the multiple-access mechanism which still can be used for these numbers. Other solutions – hybrid WDM/TDMA, UDWDM, or active-plus-passive hybrid – exist, but either lead to higher cost and power consumption, or require active sites which may contradict site-consolidation programs of network operators.

It is essential to clarify carefully the requirements for next-generation access with regard to per-PON client count and maximum reach. The question if WDM filters are allowed in the ODN (instead of power splitters/combiners) also has to be answered. If in particular client count does not exceed ~320, and a passive, filter-based ODN is accepted, the most efficient solution with regard to both, cost and also power consumption, is a simple WDM-PON.

3. Metro Networks

In scalable metro networks, switching and multiplexing functionality should be provided on the lowest-possible layer. The remaining higher-layer functionality should be concentrated in fewest possible sites for highest operational efficiency. Overall, a modular metro node architecture is desirable which allows a flexible combination of optical bypass, electronic multiplexing/aggregation and layer1/2 switching functions in a single network element. Fig. 3 depicts a block diagram of such generalized node architecture [4].

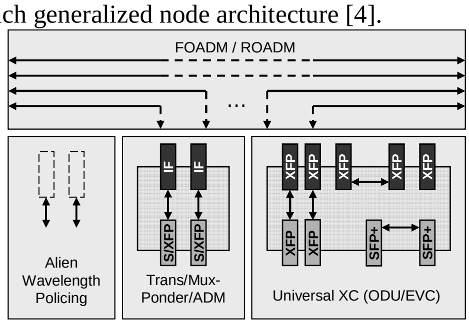

Fig. 3. Generalized node architecture. In the photonic layer, connectivity is provided by reconfigurable (ROADM) or fixed (FOADM) optical add/drop. In the electrical layer, colored clients ("alien wavelengths") can be directly connected. Gray or colored clients alternatively can be connected through transponders, groomed by muxponders and add/drop multiplexers (ADM), or flexibly cross-connected (XC: Cross connect) on ODU and/or EVC layer (XFP: 10 Gigabit Small Form Factor Pluggable, SFP(+): Small Form Factor Pluggable (Plus), IF: Interface)

On the optical layer, MD- or D2-ROADMs are used. In certain sites with low optical add/drop traffic, these can be substituted by optical filter based FOADMs to save capital expenditures (CapEx). ROADMs do not only provide bit rate transparency, they also support an automated reconfiguration. This feature simplifies the provisioning of new optical circuits and supports an optical re-routing in case of link failures or scheduled maintenance actions. To enable more flexible reconfiguration capabilities, it is desirable that the add/drop ports can randomly access any wavelength from any trunk port. This functionality is sometimes also referred to as a color-less and direction-less add/drop. On the electrical layer typically a mix of TDM circuits as well as packet services is running on top of the photonic backbone. Many carriers ask for hybrid packet-optical transport platforms (POTPs) to efficiently combine MPLS for business VPN and residential services, high bandwidth, premium Ethernet virtual circuit (EVC) services, and ODU services for an efficient transport of ≥ 1 Gb/s leased line services. The current standardization effort of ODUflex allows a highly efficient co-existence of MPLS and ODU traffic on the same optical infrastructure. The merit of such hybrid packet-optical switch architectures was evaluated for core networks, and the results are summarized in the next section.

4. Core Networks

Next-generation optical core networks provide the infrastructure for a reliable delivery of high-capacity packet and circuit services. To keep pace with steady traffic growth, Multi-Tb/s networks are required in which packet flows, time-division multiplex (TDM) circuits and dense wavelength division multiplex (DWDM) wavelengths can be seamlessly transported and switched. Recent progress in transport technologies, specifically the evolution towards cost-efficient colorless, directionless, and contentionless ROADM architectures, allows such networks to be built and operated in a scalable, flexible and automated way [5]. An important aspect is the design of the multilayer network combining these three architectures. E.g., the authors in [6] show that lightpath bypass can save from 25% to 45% in power consumption compared to a non-bypass design.

In [7] the authors compared in a case study three different node architectures for packet/circuit/wavelength switches suitable for next-generation optical core networks: parallel packet and circuit switch, overlay packet and circuit switch, and hybrid packet and circuit switch (Fig. 4). The case study shows that node architectures which integrate packet (MPLS) and circuit (ODU) switching by means of a single, protocol-agnostic switch matrix are most flexible in the assignment of circuit and packet traffic, provides the minimum number of optical interfaces, and allows the best exploitation of the available fiber capacity.

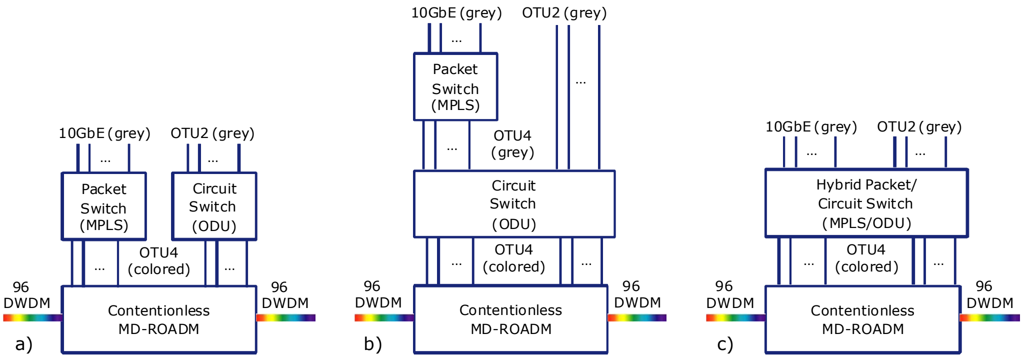

Fig. 4. Network node options: a) parallel, b) layered, c) hybrid packet & circuit switch. All DWDM channels are using 100 Gb/s line rate.

5. Conclusion and Outlook

The key for providing cost- and energy-efficient packet transport in Access, Metro and Core networks is to maximally utilize the benefits of the optical infrastructure. Simple WDM-PON in access networks, and flexible, color-less, directionless and contention-less ROADMs with integrated hybrid packet / circuit switches in metro and core networks are the key building blocks. In future, software-defined optics with gridless channel allocation, variable data rate, and adaptive modulation, forward-error-control (FEC), and equalization in combination with a powerful control plane will provide a simplified, scalable and automated bandwidth delivery for packet and circuit services up to 1Tbit/s per optical transport channel.

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