Optical Networking Trends and Evolution

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Abstract: Control-plane enabled 100G transmission over a flexible optical layer is becoming a commercial reality in optical core networks. This paper discusses the drivers and challenges as well as future trends and further developments.

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1. Introduction

The undisputed explosive growth in bandwidth demand in both carrier and enterprise optical core networks is driven by mobile/wireline video applications. This growth is enhanced by the evolution of central offices to mega-datacenters employing multi-10-Tb/s switches and routers. Today, the bandwidth demand is being commercially addressed with 100G channel rates employing coherent transmission technology, advanced modulation formats and digital signal processing, together with a flexible underlying optical layer that employs advanced amplification and ROADM technologies. This solution also utilizes control planes to facilitate provisioning, protection/restoration and bandwidth optimization.

Partially based on standards like G.709 Optical Transport Network (OTN) [1], optical module and electrical interface definitions by the Optical Internetworking Forum [2] and Control Plane definitions by the IETF [3], these technologies appear to result in cost-efficient implementations and a sustainable value chain, which has yet to be proven. The tremendous cost pressure throughout the whole industry - from component over systems to networks addressing both CAPEX and OPEX - is the key driver moving forward; consequently, all further product evolution needs to deliver lower cost/bit solutions. Going forward, the industry should take a step back and focus the wide range of networking requirements on dominant scenarios, identify the major cost drivers and tackle these. The key areas are : 1) future channel coding and modulation techniques; 2) the underlying optical layer employing efficient amplification and switching, 3) management and control; and 4) potential multi-layer integration.

2. Channel Coding and Modulation

The evolution in high-speed electronics and signal processing was the key enabler that led to current coding and modulation technologies. Research, standards and commercially available realizations converge on 100 Gb/s via 25GBaud polarization multiplexed quadrature phase shift keying (PM-QPSK) using advanced forward error correction and signal processing algorithms. These bandwidth efficient realizations allow for high tolerance against dispersion and enable an extended reach of 2000+ km [4]. There's an ongoing industry discussion whether there is market space for 40 Gb/s transmission channels. This market is expected to diminish if cost targets of 100 Gb/s realizations are met.

Nevertheless, there is definitely room for a more cost-efficient 100Gb/s implementation using multi-carrier modulation of 4 x 28 Gb/s combined with directly modulated laser and receiver arrays used in a manner similar to that of standard 100 GbE CFP transceivers [5]. This implementation enables a reach of up to 600 km, while costs, power consumption and footprint remain significantly below those of the PM-QPSK variant. It can also be deployed over existing infrastructure, and it is for these reasons that experts foresee a dominant role in medium-haul networks in the future.

Where do we go from here? Comparing coding, modulation and signal processing in optical systems with the evolution of radio transmission technologies provides an interesting foundation for future outlooks. In radio technology after the analog era, the key technology steps have been the use of QPSK with a code rate of 1:2, a code efficiency of 0.5 and a resulting spectral efficiency of 1 Bit/s/Hz in the 1970s Through multiple evolutionary steps, technology development became saturated around the year 2000 with 512-QAM and a net spectral efficiency of 11 Bit/s/Hz. Despite evolving coding techniques, the required signal-to-noise ratio limits the overall link budgets. Since the early part of the new millennium, the technology focus has been on cost efficiency and flexible implementation by inventing software defined radio (SDR) and employing techniques like hitless adaptive modulation, both of which allow a flexible adaptation to changing channel conditions, including environmental conditions such as rain. Driven by the possibilities in electronics, the evolution of optical coding and modulation is more than a decade behind, yet it follows similar steps. However, there's one fundamental difference when comparing radio to optical, which is the availability of spectrum; there's only one spectrum to be used, but usually multiple fibers that require its use. We need to remind ourselves that cost efficiency is the primary target, not just pure bandwidth efficiency over a single fiber.

Nevertheless, we should focus optical evolution on flexibility and not solely on the specific realization of 400Gb/s or 1000Gb/s channel rates with OFDM or n-QAM. Translating SDR into software defined optics (SDO) would imply the use of universal transceivers coupled with flexible baseband processing [6]. It would enable a flexible signal adaptation to QoS, application and channel requirements using multi-level and/or multi-carrier modulation techniques. It would therefore enable optimum network utilization. Furthermore this could lead to a a generalized optical interface with significant cost advantages due to a wide range of applications and large expected volumes.

The key enablers for this evolution are further advances in affordable CMOS-based high-speed electronics, photonic integration, as well as hybrid photonic/electrical integration.

3. Optical Layer Technologies

Today's underlying optical-layer technologies are based on integrated or stand-alone optical amplifiers (Erbium-Doped Fiber Amplifiers (EDFAs) and/or Raman amplifiers) and Reconfigurable Optical Add/Drop Multiplexers (ROADMs) based on Wavelength Selective Switch (WSS) or Planar Lightwave Circuit (PLC) technology. The nodes are colorless and directionless, i.e., they provide the flexibility to direct any flexible wavelength channel to any direction/degree of the node. Overall, this enables flexible ring and mesh architectures.

One key evolutionary step in optical technology is extending the nodal architectures to be colorless, directionless and contentionless, i.e., to be able to switch **any** wavelength over **any** port to **any** direction (also known as the "tripleA"). In order to achieve this, an additional switching plane within the add/drop path of these nodes must be implemented [7]. Another important aspect in the technology evolution is the move to so-called gridless functionality, whereby a programmable filter allows for flexible channel bandwidths that may vary over the spectrum. The challenge is to implement these steps in a cost-efficient and deployable manner with enablers like Liquid Crystal On Silicon (LCOS) and MxN WSSs. The complexity of these nodes requires measures that significantly simplify the installation and commissioning processes and that makes mandatory the use of control planes for provisioning and planning.

The use of the above-described coherent coding and modulation techniques allows for simplified link design, as dispersion compensation techniques within the link are no longer necessary since single-stage EDFAs or hybrid RAMAN/EDFAs are used. The remaining challenges lie in improved OSNR performance and proper transient control mechanisms, while the ultimate target would be parametric amplifiers that could handle fast-changing input powers and therefore fully support the targeted flexibility. Furthermore we need advanced wavelength and fiber monitoring techniques to support management and control of the enhanced complexity.

With these latest developments, we have not yet achieved the necessary cost points to enable mass deployment throughout all areas of the optical layer. Therefore, our key challenge remains to enhance the underlying component technologies to drive significant cost efficiency.

4. Protocols and Multi-Layer Integration

The transport layer with wavelength and time division multiplexing (TDM) properties is well defined by ITU G.709,and the most recent extensions to the standard created a true multi-service technology by improving the handling of Ethernet and other packet services through the definition of GbE-, 10GbE- and 100GbE-based and arbitrarily sized payloads [1]. A new generic mapping procedure (GMP) allows for a more flexible client mapping and ODU multiplexing. The remaining challenge is to efficiently interwork with IP/MPLS layers, which may be addressed by Ethernet or MPLS technologies to complement the OTH functions.

The latter arises out of the discussion of whether IP/MPLS/Ethernet-based services should be fully integrated with transport technologies or not. This remains an ongoing industry discussion. To resolve this question, we must first take a step back and ask ourselves why this would be beneficial. Despite organizational challenges at carriers and despite the transition from TDM to Ethernet in backhaul and service delivery, a key issue arises from the lack of channelized interfaces on routers that facilitate efficient bypass and interworking with a flexible transport layer. Carrier Ethernet-based services and networking are defined to include rich OAM and proper resilience mechanisms that are now commonly being integrated into transport nodes referred to as packet optical transport.

MPLS-TP (MPLS transport profile) as a transport-oriented MPLS variant aims at delivering packet-transport network services by combining MPLS packet experience with the operational experience and practices of optical transport networks. The main characteristics of MPLS-TP are: Connection-orientation, fast protection capabilities and enhanced OAM capabilities. MPLS-TP does not need a control plane for provisioning, and it can also be configured manually or through network management software. It has yet to be proven whether MPLS-TP is the right approach versus Carrier Ethernet despite the benefits of direct interworking with MPLS.

Nevertheless it is obvious that significant saving potential lies in the integration of multiple layers in a single solution. The depth will vary from a simple integration of colored interfaces in higher layer devices up to single fully integrated solutions, as will the complexity of the overall set-up. The optimum demarcation between the layers may be different for different target applications and will become clearer in the upcoming years.

5. Management and Control

One of the key tasks going forward remains the provisioning and monitoring of paths across multiple layers with increased flexibility and complexity.. In addition to the usual aspects of displaying, maintaining and assuring infrastructure and services, scalability and the easy integration into OSS environments continue to be focus areas of the industry. The use of GMPLS-based control planes in an integrated or multi-layer fashion is mandatory not only to complement network and service management systems, but also to plan current and next-generation optical core networks.

A standards-based control plane implementation covers automated network/network element discovery, end-to-end path computation and signaling/provisioning functions. OSPF-based routing modules, along with traffic engineering (OSPF-TE) and GMPLS extensions (GMPLS-TE), are used to discover the topology and capabilities of the data plane. A path computation element (PCE) as defined by the IETF RFC 4655 [3] relies on constrained-based shortest-path-first (CSPF) algorithms to calculate end-to-end paths fulfilling service, network and redundancy requirements. A signaling component using the resource reservation protocol (RSVP), along with traffic engineering (RSVP-TE) and GMPLS extensions (GMPLS-RSVP), can be used to allocate and provision resources across an end-to-end path. It can also automate the configuration of ROADM devices and facilitate end-to-end equalization of optical power levels along the service path. By adopting a GMPLS peer model, for example, the interworking between a GMPLS-controlled transport network and the IP/MPLS routers as clients is easily made possible.

The latest extensions of the PCE architecture, in particular, enable a wider and more flexible use of GMPLS control planes. The applications within the management and control of transport networks for wavelengths, G.709 and a potential Ethernet layer is state-of-the-art today. The key future challenge arises with the further integration of network layers and the aspects of multi-layer control plane and PCE. Despite a significant amount of draft standards and RFCs, the use of these in real implementations is far behind actual implementation, as scaling and realization aspects haven't always been properly taken into account.

A full implementation of top-to-bottom multi-layer path computation and provisioning remains a hot topic for both research and commercial solutions. However, we should take a step back and focus on more realistic approaches with firmly defined relationships between layers and some heuristic user guidance in order to achieve significant steps forward.

6. Conclusion

We have seen dramatic technology changes with respect to optical networks within the past years. However, we are at the beginning of the evolution towards a fully flexible, programmable and most importantly affordable optical network. Software-defined optics over a flexible optical infrastructure with proper integration of multiple network layers and automated control are on the horizon.

7. References

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