Optics and the Challenge of Carrier Network Transformation

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Abstract

The transformation of network architecture towards a multi- service packet network is explained and the dependencies between new optical technologies and network architectures are discussed.

Optical Networks (Practical) State of the Art

The majority of optical systems in use today were installed in the period from 1999 to 2001 (also referred to as systems of the second generation). Such systems enable the simultaneous transport of 60-80 channels in the backbone network with a maximum of 10Gbit/s per channel via one optical fiber. The principle of massive parallel transmission of several wavelengths (or channels, these terms are used interchangeably in the context of this paper) is referred to as wavelength division multiplexing (WDM). WDM is and will remain the mainstay of optical transport for the years to come, being the enabler of all Internet-based applications and services.

The optical distance which is the transmission range before electronic regeneration of these 2nd generation WDM systems is typically about 600 km via standard single-mode fiber (SSMF) with dispersion-compensated fibers (DCFs) being distributed periodically along the routes in order to restrict the impact of chromatic dispersion. In the national network of Deutsche Telekom (DT) these systems are mainly used as point-to-point systems, i.e. without switching or crossconnecting elements like optical add-drop multiplexers (OADMs). The introduction of the 2nd generation of WDM systems did include a transition from 2.5Gbit/s to 10Gbit/s per channel, whilst the Polarisation Mode Dispersion (PMD) proved to be a limiting factor, which could be avoided by measuring and selecting the fibers concerning this system generation. These WDM systems were meant to avoid emerging fiber bottlenecks and to benefit from cost advantages thanks to optical amplifiers, which can be used much at a more favourable price than SDH/SONET regenerators (SDH, Synchronous Digital Hierarchy/ SONET, Synchronous Optical Network). The optical transmission systems are used as a server layer for the connection of SDH cross-connects, ATM switches and IP routers, as well as for manually configured “leased lines“. Most of the traffic of service networks, for example ATM, PSTN is multiplexed and groomed by SDH/Sonet and than transported by optical channels. However, depending on the traffic demand the IP nodes are either connected directly to the WDM layer or use the multiplexing functionality of SDH. (Figure 1. left side)

Most of the current WDM systems have usually been equipped with transponders, using the SDH/SONET frame format. Therefore they were restricted regarding their control and monitoring functions. Regarding the optical paths only a monitoring per section on the basis of some SDH overhead bytes was provided, but no end-to-end monitoring was supported.

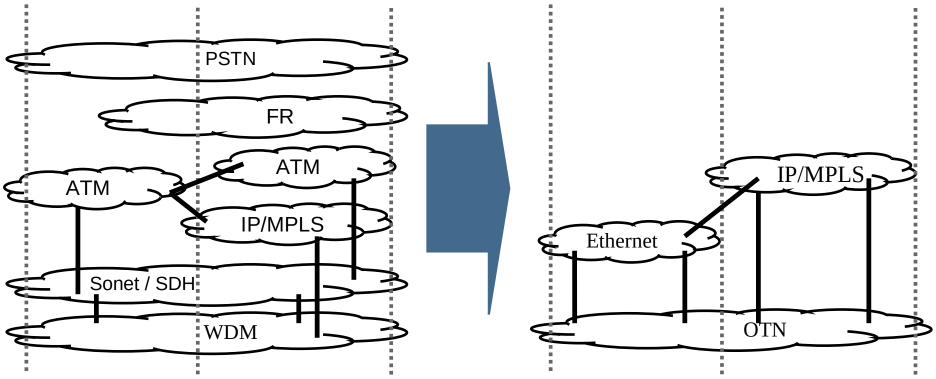

Figure 1: Transformation of the functional network architecture

Transformed Networks

The basic concept of network transformation is depicted in figure 1. As shown on the left side of the figure, currently most of the carriers worldwide operate multiple network-service platforms e.g. PSTN, IP, ATM, FR and multiple transmission networks e.g. Sonet/SDH, WDM simultaneously. This kind of simultaneous operation has been identified as a major driving factor for operational expenditure which is related to both the number of network layers and elements itself but also the various numbers of operation systems. Carriers are trying to reduce the number of functional layers, moreover carriers working on network transformation rely on optics in order to reduce costs by reducing the number of operational sites. From a technical perspective the key concept of the transformed network is a packet switching and forwarding paradigm enabling easy multi-service integration especially with respect to various access technologies and customer devices. Moreover the transformation to full packet switching paradigm promises an increase of network efficiency, because analysis of current TDM circuits has shown a very low utilisation of the circuits. The right side of Figure 1 shows a proposal of how the transformed network architecture may look like. The key components of the architecture are IP / MPLS in the backbone, Carrier Ethernet, and optical networks, i.e. OTN [1]. OTN provides cost efficient, very reliable, high capacity optical channels that can be managed and monitored in a network-operator fashion. The channels serve to connect high capacity Ethernet switches, to connect Broadband IP/MPLS routers and to produce broadband leased lines. Depending on overall traffic load GMPLS control integration might be useful as well the Carrier Ethernet functionality is mainly used to aggregate (i.e. statistical multiplexing) and backhaul traffic of residential customers, to separate different services and service classes, and to produce business services as there are Virtual-Private-Line- and Virtual-Private-LAN- services.

The Optical Transport Network (OTN)

The physical layer has to handle the transmission over the physical media which includes the representation of the Bytes, line-coding, modulation schemes, signal power etc. From the perspective of data transmission network as described in the 7-Layer OSI model each optical channel behaves like a physical medium, therefore one could refer to optical channels as a “virtual physical medium” on a optical fibre, which is capable to transport hundreds of optical channels. The concept of the Optical Transport Network (OTN [2]) covers a large number of operator specific functionalities. The OTN is structured in a hierarchical order and is used either as an end-to-end networking entity or as point-to-point structure for OAM provisioning (Operations, Administration, and Maintenance). The basis of the OTN hierarchy is the Optical Channel (OCh), which is “analogue” in nature. The hierarchy defines three levels of a digital framing structure. The basic building block of the OTN is the Optical Channel Data Unit (ODUs). The ODU is defined as the end-to-end networking entity, comparable to an SDH/SONET virtual container. ODUs are currently defined for 3 bit rates: (ODU1: 2.50 Gbit/s; ODU2: 10.04 Gbit/s ODU3: 40.32 Gbit/s). The equivalent point-to-point single lambda frame structure is called Optical Channel Transport Unit (OTU), and the OTUs bit rates are OTU1: 2.67 Gbit/s; OTU2:10.71 Gbit/s; OTU3: 43.02 Gbit/s. Moreover the ITU-T recommendation G.709 [2] specifies a simple multiplexing of TDM into OTU1 to OTU2 and a multiplexing from OTU2 to OTU3 as well. The networking entity ODUk represents the end-to-end transparent payload part of the digital content of a single wavelength; it has a frame structure with overhead, payload and an area for Forward Error Correction (FEC). The optical channel is a digital signal, a part of it (the ODUk) being transported as an end-to-end entity via a wavelength, while overhead processing has to be done electrically. Following this framework there is no need within the network for a particular matrix technology implementation (optical or electrical) for switching of optical channels.

Kommentar [TZ1]: Nicht ganz klar, was gemeint war…

The monitoring functions allow efficient maintenance by the operators such as path trace test, loop installation, alarming on several OTN–levels, and localisation of faults. Furthermore, action on quality degradations (e.g. signal degradation) is permitted, and thresholds indicating quality impairments are configurable.

Section, trail or path wise protection is possible according to the needs and agreements of the operator allowing fast recovery of the traffic. An extended recovery mechanism throughout the network is restoration. Instead of using predefined protection routes the recovery path is just allocated after the failure. Restoration provides a high availability and over all a more efficient use of resources and is under definition in ITU-T as part of the ASON/GMPLS (ASON Automatically Switched Optical Networks, GMPLS Generalized Multiprotcol Label Switching) In general the following key advantages of this digital framing structure, the Optical Transport Network (OTN), can be identified:

- The transport is relatively independent of the payload; and flexible mapping of different payloads is supported,
- OTN can multiplex high data rates up to 40 GBit/s
- OTN supports carrier class monitoring and management function for large networks,
- OTN can be configured dynamically by the control-plane technology to provide fast restoration and other automated functions for provisioning. These capabilities are consistent with the ITU-T ASTN definitions (ASTN: Automatically Switched Transport Network).

Carrier Class Ethernet

Ethernet is massively deployed in as Layer 2 technology in Local Area Networks (LAN). However, due to the cost attractiveness of a huge market volume and due the simple “Packet Switching Paradigm” Ethernet will play a key role in carrier network architecture [3]. Generally Ethernet technology promises more cost effective switching of frame/packet based traffic than IP/MPLS technology. Hence, introducing L2/Ethernet can offer value added L2 services, and reduced IP data transport in core and metro by replacing IP routers by cheaper

Ethernet switches. On the other hand the classical Ethernet known from LAN and operating in broadcast mode only does not fulfil scalability and operational requirements of networks operator. Currently standardization bodies are working to overcome the hurdles of classical Ethernet and extent the functionalities with respect to

- OAM - principles as usual in carrier networks,
- Extension of label spaces in order to overcome the limit of 4096 VLAN-identifiers,
- Introduction of service classes and capabilities to control service level agreements,
- Introduction of routing principles that overcome the topology limitations of spanning and rapid spanning tree protocol,
- Improvement of switch building practice in order to achieve higher switch-throughput, very fast table look-up processing and high reliability,
- Increasing of link speed towards 100Git/s (or even 40 Gbit/s) and towards parallel links.

Currently there are two major trends of Carrier Ethernet, an extension of the IEEE switch/bridge approach with basically maintain the principle of broadcast domains on one hand side and fully connection oriented point to point approaches concentrating on Ethernet virtual connections on the other hand. Regarding Ethernet functionalities in carrier networks a number of first deployments can be observed all over the world, most of which are related to the offering of broadband access and triple play services. However, these solutions are currently not designed for a fully transformed network, mainly due to the lack of functionalities listed above, but they give a clear indication about the general trend.

Optics in the Backbone: IP/MPLS over Optics

An additional interesting aspect for optical networks becomes obvious, because the question arises if IP backbone networks with some Terabit per second throughput can really be realized efficiently with the architectures used today. For such envisaged traffic loads the bandwidth of MPLS-tunnels will reach Gbit/s. These tunnels can be produced in an easier and more cost-efficient way with optical techniques than with packet forwarding or label switching methods - assuming a cost relation of 1:3 between optics and IP, a ratio which basically remained constant over the last couple of years. The tunnels can be used to provide additional functionalities as described GMPLS framework of the IETF: The optical tunnels do not have to be produced purely on an optical layer, an OTN frame is rather to be preferred due to standardized monitoring, as described in the chapter on OTN, optical here is merely a synonym for high bandwidth granularity >> 1Gbit/s of the configurable data entities.

From the perspective of IP a control integration (which is the implicit meaning of "tunnel") is needed in order to achieve a simplified view on the network topology and to simplify network operation. Moreover regarding the hardware the integration allows to reduce the amount of costs for the interfaces between the IP routers and the optical system, while pluggable modules, coloured interfaces, or also multi-channel interfaces are applied (Figure 2).

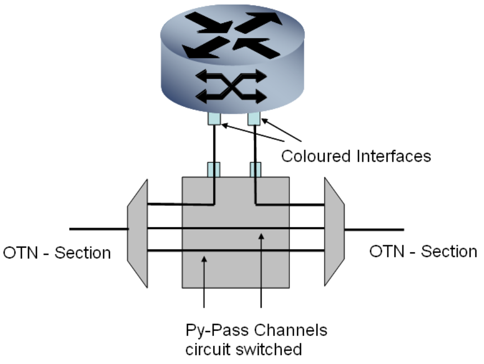

Figure 2: Backbone IP-OTN Inter-working

Challenges of Optics

Optics will play a key role in future networks because compared to switching/routing costs transmission costs have been decreased dramatically (about the factor or 1000 in the past decades). Due to the opportunity of very cost efficient long distance transmission network architects can redesign the whole network, e.g. very large aggregation areas, optical bypassing of switches, and the reduction sites with switching elements can be realised. OTN provides cost efficient, very reliable, high capacity optical channels that can be managed and monitored in a network-operator fashion. The channels serve to connect high capacity Ethernet Switches and to connect Broadband IP/MPLS routers and to produce broadband leased lines. Currently the major challenge is the consideration of optics for the overall-network design and the integration of optical networks with Carrier Ethernet and IP/MPLS respectively.

References

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