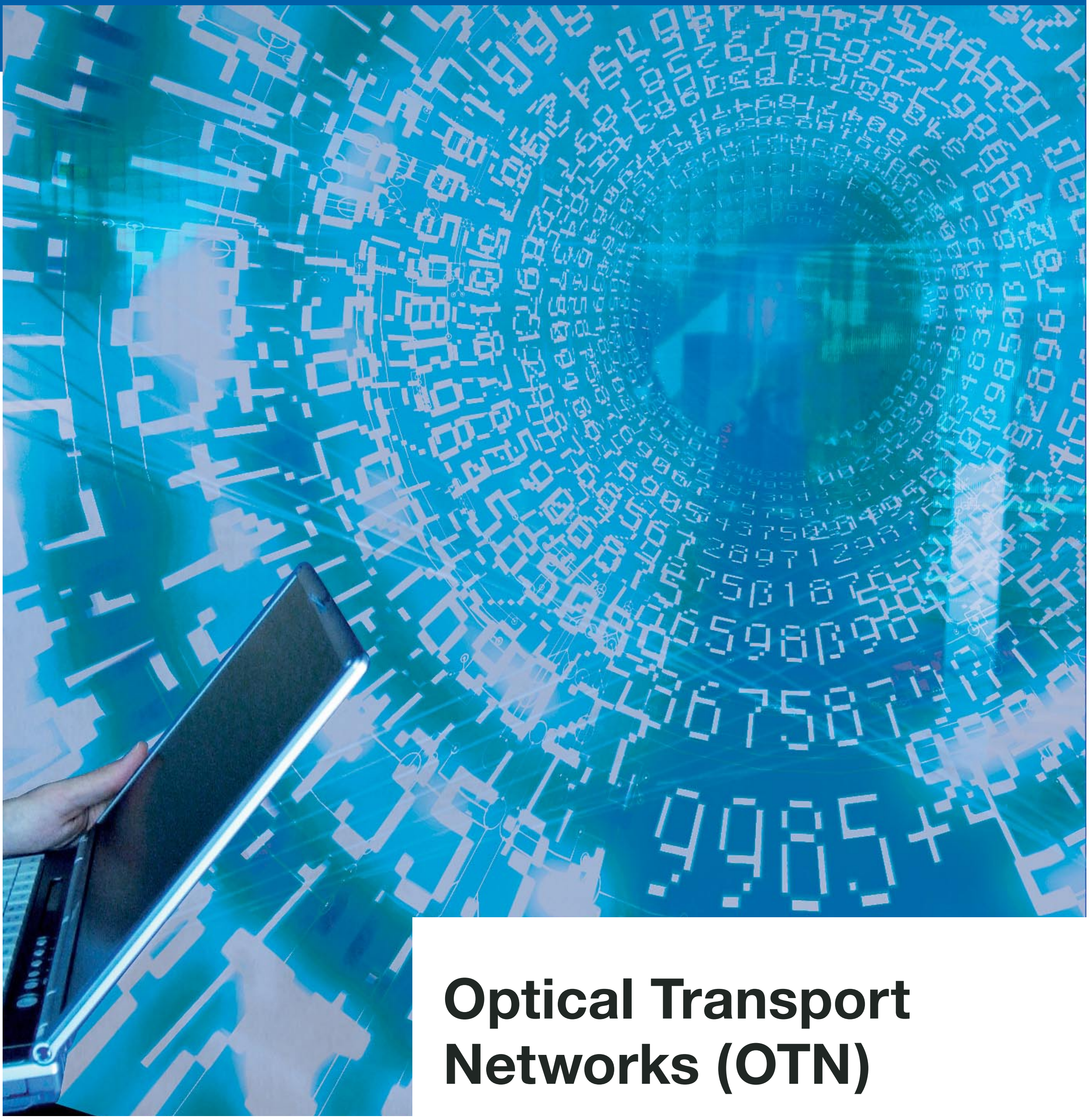
ITG-Positionspapier



Optical Transport Networks (OTN)

Technical Trends and Assessment

VDE

ITG-Positionspapier

Optical Transport Networks (OTN)

Technical Trends and Assessment

Matthias Berger, Lucent Technolgies
Bernhard Edmaier, BT (Germany) GmbH & Co OHG[1]
Gert Eilenberger, Alcatel SEL AG[1]
Clemens Epple, BT (Germany) GmbH & Co OHG[1]
Hans Martin Foisel, T-Systems[1]
Andreas Gladisch, T-Systems[1]
Gert Grammel, Alcatel SEL AG[1]
Klaus Grobe, ADVA AG Optical Networking[1]
Günter Grüell, Alcatel SEL AG
Andreas Iselt, Siemens AG[1]
Monika Jäger, T-Systems[1]
Ulrich Kohn, Ericsson GmbH (formerly Marconi Communications GmbH)[1]
Karl-Heinz Mundt, Intel GmbH
Kristof Obermann, Arcor AG & Co. KG[1]
Jan Späth, Ericsson GmbH (formerly Marconi Communications GmbH)[1]
Mario Stoltz, Intel GmbH
Fritz Joachim Westphal, T-Systems[1]

Impressum
Herausgeber:
VDE Verband der Elektrotechnik
Elektronik Informationstechnik e. V.
Stresemannallee 15 | 60596 Frankfurt/M.
Tel.: +49 69 6308-0 | Fax: +49 69 6312925
www.vde.com | service@vde.com
Gestaltung: KELLERMANN · GRAPHIK DESIGN
Bild Titelseite: Siemens
March 2006

[1] Member of the VDE/ITG study group „Photonic Networks“.

Abstract

This paper is a joint work of the VDE/ITG study group “photonic networks” and deals with the evolution of transport networks beyond SDH. Firstly, the drivers are identified which lead to an increase of both, the total capacity and switching granularity of transport networks. The demand for higher capacity transport pipes has initiated the development of new mapping schemes and payload structures optimised for capacities significantly exceeding the highest payload capacity of SDH. In response to this, ITU-T has developed a set of standards for the Optical Transport Network (OTN). This paper describes the fundamental functionality and evaluates the features of OTNs. Further, migration scenarios from SDH to OTN networks are pointed out.

1. Market Drivers

After a period of tight budget restrictions with minimum investment in transport networks, many operators are investigating into strategies to expand the capacity of their networks and at the same time look for ways to benefit from applying latest technology. As technical progress has not slowed down in a similar way like investments have, there is a significant potential from applying such advanced technologies not just for reducing cost per transported bit but also to extend the service portfolio.

Besides the availability of new technologies, there is also a change in service requirements, which needs to be considered when discussing network evolution. The following list outlines recent trends.

1. Broadband access technologies, regardless if wired (e.g. xDSL, FTTx) or wireless (IEEE802.11, WiMAX, UMTS) are going to increase the general bandwidth requirement and to erode the 64 kbps and 2 Mbps leased line market.

2. This trend will further be boosted by the migration from circuit-switched voice services to Voice over IP (VoIP), and in particular the migration towards VoIP in enterprise networks. This is resulting in a bandwidth market requiring coarser granularity transport services, as many flows are aggregated into broader streams at the edge of the network. However, it needs to be noted that 2 Mbps transport including distribution of high quality synchronization clock as required by mobile base stations will still be required in the future.

3. Enterprise networks are migrating towards Gigabit-Ethernet (GbE), replacing ATM- and FDDI-based solutions. Ethernet Private Line or Ethernet Private LAN services are typical examples for new network services enabling customers to interconnect their Ethernet-based enterprise networks.

4. Medium and large business, authorities and universities operate high capacity mass storage systems, which need to be accessed from any site and which need to be backed-up. This creates a high demand for Fiber Channel and GbE/10GbE transport services. Bandwidth requirements are quite significant and can exceed hundreds of gigabits per second. A further evolving and bandwidth-demanding application is Grid Computing, which requires high speed interconnections between clusters of computers.

5. In a highly competitive, de-regulated market environment even major operators frequently use leased lines if no own infrastructure is available, rather than building own transmission systems. Such carriers' carrier services have generated an increasing market for high capacity fixed bandwidth services with bandwidth requirements well above VC-4.

These new service requirements change both, (transport) network designs and optimum choice of applied technologies. As a consequence, new technologies are required to provide some of the requested features and functionalities. The demand for high capacity transport pipes initiated the development of new mapping schemes and payload structures optimized for capacities significantly exceeding the highest payload capacity of SDH (150 Mbps for a VC-4 container). Multi-operator networking results in the need for standardized interfaces as well as a need for transparent SDH transport services rather than VC-4 transport.

In response to this, ITU-T developed a set of standards which meet those emerging needs. The Optical Transport Network (OTN) embraces the electrical and optical layer of such transport networks and allows seamless integration and operation of both network domains.

Today, application of OTN is mostly with DWDM transport. There is no massive deployment of OTN cross-connect systems yet. However, products that support OTN standards to various degrees are already available on the market and even broader availability of OTN-based product lines and feature sets is expected for the very near future.

2. OTN Technology

2.1 Layers of the OTN

The new OTN (often also referred to as the Optical Transport Hierarchy, OTH) is specified by ITU-T in various Recommendations (e.g. G.872 on architecture, G.709 on frames and formats, G.798 on atomic functions and processes). It combines electrical and optical multiplexing under a common standards framework. The electrical domain is structured in a hierarchical order just like SDH/SONET. The optical domain is based on DWDM multiplexing technology but provides standardized interfaces and methods to supervise and manage the network. The layered structure of OTN is shown in Fig. 1.

The OTN hierarchy is based on the Optical Channel (OCh). The OCh payload is carried over a wavelength. Different from legacy DWDM systems, the structure of this signal is standardized. A common Optical Supervisory Channel (OSC) is used to transport the overhead information of the OCh but also provides maintenance signals and other management data.

An OCh payload consists of an electrical substructure. The Optical Channel Transport Unit (OTU) is the highest electrical multiplexing level and includes a Forward Error Correction (FEC) function. It is applied between points in the network, where the signals are converted from the optical to the electrical domain. The Optical Channel Data Unit (ODU) carriers an Optical Channel Payload Unit (OPU). The client signals are mapped into the OPU, which is not processed at intermediate sites of a transport network.

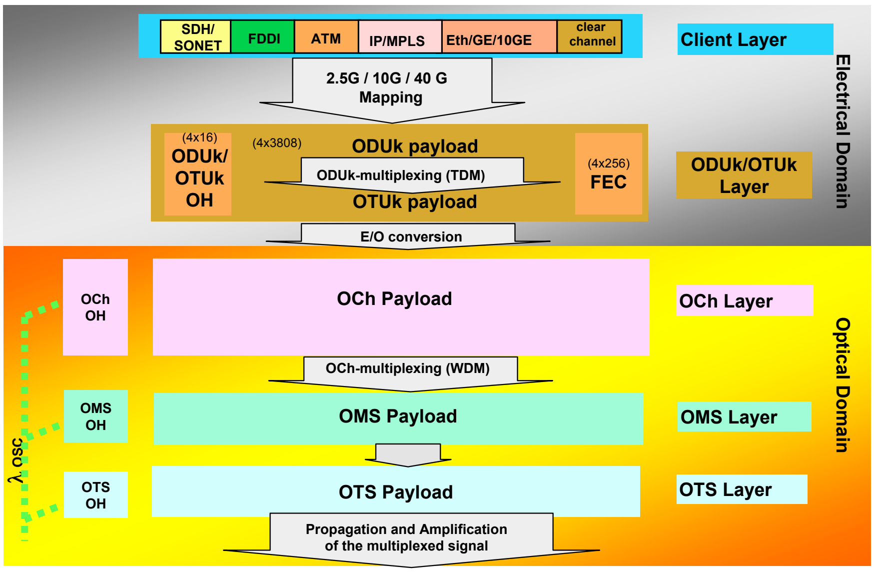


Fig. 1:
General Layering and Monitoring of OTN (G.709)

The ODU signals are defined as the end-to-end networking entities, comparable to the former SDH virtual containers. They are currently defined for 3 bit rates:

- ODU1: 2.50 Gbps
- ODU2: 10.04 Gbps
- ODU3: 40.32 Gbps

These are mostly referred to as 2.5, 10, and 40 Gbps.

The bit rates of the Optical Channel Transport Unit (OTU) are:

- OTU1: 2.67 Gbps
- OTU2: 10.71 Gbps
- OTU3: 43.02 Gbps

Again, these are mostly referred to as 2.7, 10.7 and 43 Gbps. The architecture and the overhead functions of the OTN are very similar to what is known from SDH. The frame structure contains 4×4080 bytes regardless of the bit rate. This implies that the frame duration is not constant like in SDH but varies with the bit rate of the actual signal.

Multiplexing of several wavelengths each carrying one OCh by means of WDM technologies creates the optical entities Optical Multiplex Section (OMS) and Optical Transport Section (OTS). The OMS layer refers to sections between optical multiplexer and demultiplexer, and the OTS layer to sections between optical amplifiers. An Optical Supervisory Channel (OSC) is implemented on a separate wavelength in order to transport supervisory and maintenance signals of the optical sublayers.

Where WDM technology is mainly needed for the extension of transport capacity, it also represents an additional physical layer in the network. Previously only point-to-point DWDM links and metro-WDM rings were possible. Building a real “all-optical network“ with only few electro-optical conversions for signal regeneration also requires the implementation of similar operation and maintenance functions as provided in SDH/SONET networks, like cross-connection, fault location, and protection switching/restoration on the optical level.

This was the reason why the concept of the Optical Transport Network was brought into ITU-T. This transport technology adds a new flexible, economic network layer to current SDH/SONET networks and DWDM systems, which allows for a managed network at a wavelength granularity.

2.2 Mapping / Adaptation of Client-Signals

While SDH signals can be mapped directly into OTN, the mapping of arbitrary L2 signals into the OTN is based on the Generic Framing Procedure (GFP) [3]. A summary of GFP is given in [4], [5]. GFP provides, for the first time, a standardized means for mapping a wide variety of (Layer 2) data signals into SDH frames or ODU frames. Client signals may be Protocol Data Unit (PDU)-oriented (e.g. IP/PPP or Ethernet MAC) or block-code-oriented, constant-bit-rate streams such as ESCON, FICON, or Fibre Channel (FC). Currently, two modes of client signal adaptation are defined for GFP: a PDU-oriented adaptation mode, referred to as frame-mapped GFP (GFP-F), and a block-code-oriented adaptation mode, referred to as transparent GFP (GFP-T).

With GFP-F, a client signal frame is received and mapped in its entirety into one GFP frame. In this adaptation mode, the client/GFP adaptation function may operate at the data link layer (or higher layer) of the client signal. Client PDU visibility is required. GFP-F mappings are currently defined for Ethernet MAC payloads and IP/PPP payloads. GFP-T mapping provides a block-code-oriented adaptation mode in which the client/GFP adaptation function operates on the coded character stream rather than the incoming client PDUs. With this type of mapping, block-coded client characters are decoded and then mapped into a fixed-length GFP frame, and may be transmitted immediately without waiting for the reception of an entire client data frame. This allows network applications like LAN/SAN extension services which require very low latency. GFP-T mappings are defined for various client signals, including FC, ESCON, FICON, and GbE. The mapping of payloads into an OTN Optical Channel (OCh) path is specified in ITU-T Recommendation G.709 [1].

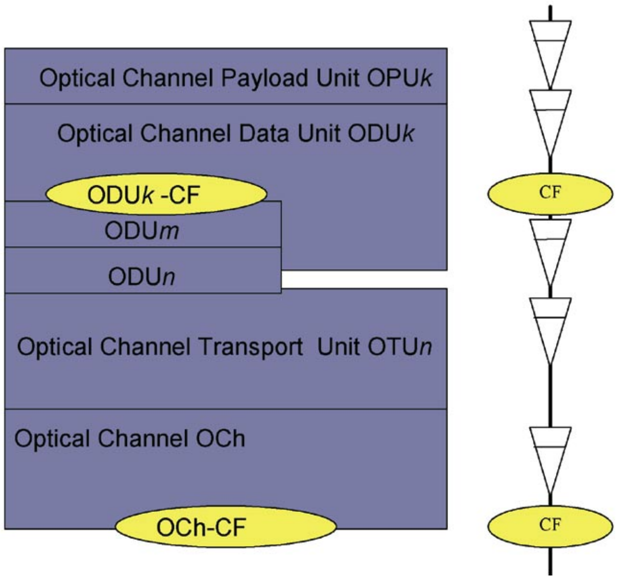
2.3 G.709 cross-connects and OADMs

Future optical transport networks will consist of high-capacity, point-to-point links in combination with cross-connects for optical channels and ODUs. This creates a truly optical network, which provides similar features as SDH/SONET networks today but extends those successful concepts towards higher capacities and optical channels.

One of the main requirements for OTN was to provide transparent transport and switching of entities like Ethernet signals and complete SDH/SONET signals. Fibers between different locations often carry multi-wavelength (DWDM) signals. The networking entity then is the Optical Channel Data Unit (ODUk with k = 1, 2, 3), representing the end-to-end transparent payload part of the digital content of a single wavelength.

The Optical Channel has a frame structure with overhead, payload, and an area for Forward Error Correction (FEC). FEC uses additional overhead for redundancy data and allows for the detection of transmission errors and even for the correction of part of these errors. The Optical Channel is a digital signal on a separate wavelength, part of it (the ODUk) being transported as an end-to-end entity. It supports any matrix technology (optical or electrical) for switching of Optical Channels. However (digital) performance monitoring is only possible in electrical switches.

Fig. 2:
Digital functionalities of OTN and levels of cross-connection (CF- Connection Function)



The digital functionalities of the OTN (G.709) are shown in Fig. 2. In principle there are two layers of cross-connecting, the (opaque) ODUk layer and the OCh layer. The reasons for the two layers are versatile. A general architecture has to support electrical and optical implementations of cross-connecting functions. Also, the definition of TDM functionalities between the three ODU-layers needs a switching layer in addition to the OCh layer in order to guarantee efficient filling of the optical channels and in order to de-couple the topology of the ODU connections from the topology of the OCh connections.

2.4 SDH Transport and Timing

Globalization of business creates a demand for global connectivity. Operators, which do not own infrastructure in all regions, have to lease capacity from wholesale bandwidth providers. If the required bandwidth exceeds SDH payload capacity, transparent STM-N transport is the preferred service to interconnect isolated network domains.

Therefore, a strong request for interface transparency on STM-N level (as a whole signal including all SOH and pointer bytes) arises. This can be solved by the introduction of OTN based networks or with a solution which is referred to as "G.modem", "OTH modem" or "SONET-over-SONET" (SoS), and which allows for transport of OTN entities over SDH/SONET networks (see chapter 2.5).

With regard to synchronization, it is important to note that in contrast to SDH, OTN network elements do not need to be synchronized with a central clock. However, it is possible to transmit clock signals via OTN, e.g. in order to synchronize remote SDH network elements (refer to G.8251).

2.5 OTN over SDH (G.modem)

In order to introduce OTN capabilities seamlessly into existing SDH networks, an ODU-over-SDH mapping functionality has been defined which is also known as "G.modem". It is defined in ITU-T G.707 §10.7 as a method to transparently switch an ODU across an SDH infrastructure. It contains the mapping of ODU1 and ODU2 into SDH structures and provides performance monitoring of the ODUk based on VC-4 Path Overhead. An ODU1 (which itself may contain a STM-16 for example) is mapped into a VC-4-17v, while an ODU2 (which itself may contain a STM-64 for example) is mapped into a VC-4-68v. Therefore STM-16 + STM-1 or STM-64 is required to transport an ODU1. For ODU2, STM-64 + STM-4 is needed.

2.6 Transparent Networking

An optical switch is a quite simple network element capable of switching traffic at coarse granularity (wavelengths, multiple wavelengths) but in a very efficient way. The traffic doesn't need to be converted into the electrical domain by expensive transponders. Hence, optical switching is a key element to cost optimize high capacity transport networks.

OTN networks with electrical cross-connects can be complemented by pure optical cross-connects, which are fully format and bit rate transparent and do not terminate, regenerate or monitor the digital content of a wavelength in any way. This approach saves costs for converting optical signals into the electrical domain and vice versa but has the drawback that in optical cross-connect locations no digital performance monitoring can be provided.

2.7 Supervision and Maintenance

Operational cost of a transport network is to a large extend determined by the management and maintenance functions provided by the network elements. SDH already today supports a comprehensive set of features and therefore is seen as the benchmark for new transport technologies.

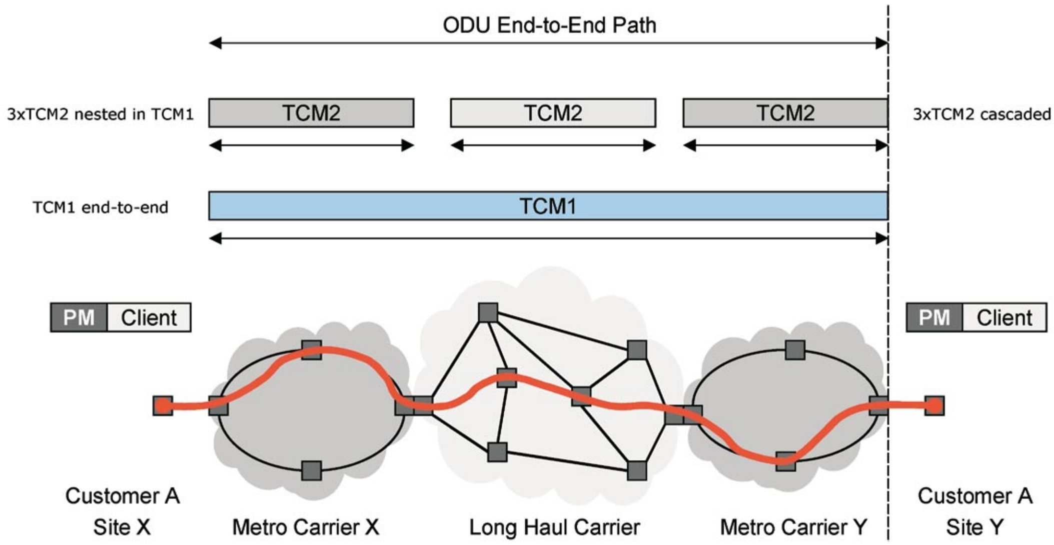
OTN standards re-use the concepts, which are applied in SDH and extend those functions, where necessary. It needs to be emphasized, that OTN provides such mechanisms not only in the electrical domain but also provides standardized mechanisms in the optical domain. This shall be explained with the simple example of Alarm Suppression. Such mechanisms are widely used in PDH and SDH to signal failures in a network so that network elements along a failed path are notified about the failure. This avoids excessive failure reports towards the network management, hence simplifies identification of a network problem. OTN extends these mechanisms into the optical domain. A failure of a multi-channel DWDM system causes the terminal at both ends of a failure to produce alarm indication signals, which inform any affected system about service failures. The Alarm Indication Signal is transported in the OSC.

Furthermore, action on quality degradations (e.g. signal degrade) is also defined. The thresholds indicating quality impairments are configurable.

An important feature of the OTN is the Tandem Connection Monitoring (TCM) within different administrative domains (e.g. vendor or operator domains). The improved TCM capability provides up to 6 independent TCM levels allowing for nested and cascaded domain monitoring. In contrast to that, SDH only provides cascaded monitoring.

Fig. 3 shows an example for signal transmission over different administrative domains consisting of the networks of two metro carriers and one long haul carrier. With SDH it is only possible to supervise the network of each carrier separately (cascaded TCM application). In addition to that, with OTN TCM it is also possible to supervise several distinct network segments in parallel. An example for this nested TCM application is shown in Fig. 3.

Fig. 3:
Example of Tandem Connection Monitoring within OTN Networks



2.8 Protection mechanisms

Mission critical applications require transport services with high availability. Network failures must not result in service interruption. Mechanisms need to be in place, which automatically detect network failures and initiate measures to re-establish the service.

Protection is a recovery mechanism based on HW functionality implemented within the network elements. The protection routes are pre-defined and pre-established. OTN standards specify several protection mechanisms. Table 1 summarizes OTN protection mechanisms in the optical domain.

Table 1:
G.872 – Protection techniques for the optical transport network

Protection technique	OTS layer	OMS layer	OCh layer
1+1 trail protection	NA	A	A
1:N trail protection	NA	A	NA
1+1 SNC/N, SNC/S and SNC/I	NA	NA	A
1:N SNC/S	NA	NA	A
Shared protected ring	NA	A	A
A - Applicable, NA - Not Applicable			

Section, trail or path protection are applied by an operator according to specific service requirements but also depending on the underlying resilience concept. In addition to the optical layer protection mechanisms there is also the possibility to protect at the electrical OTN layer e.g. OTU/ODU trail protection or ODU SNCP (standardized in ITU-T G.873.1). It is expected that the standardization applicable for the ODU layer will be extended to shared protection rings in early 2006.

2.9 Restoration mechanisms

Restoration is an extended recovery mechanism, which makes use of all available network resources to re-establish a service. Instead of using predefined protection routes the recovery path is calculated after the failure occurred. Restoration times are slower than protection times, but this mechanism can provide higher availability as services can even be restored in multi-failure scenarios.

Typical restoration times are in the order of several hundred milliseconds up to a few seconds. There are applications in mobile and fixed voice networks, which require very short protection switching times in the order of 50ms. For those applications restoration can not be used as a primary recovery mechanism, protection needs to be applied.

IP based NGN core networks can tolerate longer restoration times (typically around 200ms) as the higher layer protocols do not suffer from short traffic interruptions. OTN networks with resilience schemes based on network restoration are therefore well suited to provide high capacity transport between routers in such networks.

Restoration mechanisms are specified by ITU-T as part of the ASTN (Automatically Switched Transport Network) standards.

3. Evaluation of OTN solutions

3.1 Bandwidth Efficiency

An optical network can be analyzed with respect to the bandwidth efficiency that can be achieved. Table 2 shows the efficiency for different client signals and different mapping solutions. It should be noted that the 10GbE LAN PHY signal is not considered in Table 2 since particular effort has to be made in order to transport 10GbE LAN PHY signals (refer to section 4.5). Distinction and comparison is made for solutions using SDH contiguous concatenation, SDH virtual concatenation (VCAT), and mappings using the OTN entities ODU1 and ODU2, respectively.

Table 2: Mapping and Bandwidth efficiency

		Mapping and Bandwidth efficiency for					
		SDH contig. concat.		**SDH VCAT**		**OTN ODU1**	**OTN ODU2**
Client	**Bit rate**	**Mapping**		**Mapping**			
Ethernet	10 Mbps	VC-3	~ 30 %	VC-12-5v	~ 89 %	---	---
Fast Ethernet	100 Mbps	VC-4	~ 65 %	VC-3-2v	~ 100 %	---	---
GbE 8B/10B coded	1.0 Gbps 1.25 Gbps	VC-4-16c	~ 40 %	VC-4-7v	~ 96 %	~ 40 %	~ 11%
10GbE (WAN PHY)	9.953 Gbps	VC-4-64c	~ 100%	VC-4-64v	~ 100%	----	~ 100%
ESCON	200 Mbps	VC-4-4c	~ 32 %	VC-4-2v	~ 67 %	~ 8 %	~ 2%
(3 x ESCON)	600 Mbps	VC-4-4c	~ 96 %	VC-4-3v	~ 89 %	~ 25%	~ 6%
FC / FICON	1.062 Gbps	VC-4-16c	~ 42 %	VC-4-8v	~ 89 %	~ 42%	~ 10%
Coupling Facilities	1.062 Gbps	VC-4-16c	~ 42 %	VC-4-8v	~ 89 %	~ 40 %	~ 10%
Digital Video	270 Mbps	VC-4-4c	~ 43 %	VC-4-2v	~ 90 %	~ 9%	~ 2,7%
Serial Digital HDTV	1.485 Gbps	VC-4-16c	~ 60 %	VC-4-10v	~ 100 %	~ 60%	~ 15%
SDH STM-16	2.488 Gbps			VC-4-17v	~ 94 %	~ 100%	~ 25 %
SDH STM-64	9.953 Gbps			VC-4-68v	<100 %	---	~ 100%

Based on the efficiency values shown in Table 2, it can be concluded that a network which is only realized by OTN (G.709) will not be sufficient with respect to bandwidth efficiency for signals with bandwidth less than 2.5 Gbps. To achieve a good degree of filling of the optical channels and to meet the requirements on client formats, additional traffic aggregation is needed.

3.2 Multiplexing and Grooming

OTN (G.709) has specified multiplexing functions for multiplexing four ODU-1 signals into ODU-2, and four ODU-2 signals into one ODU-3, respectively. In order to evaluate the possibility to realize a hierarchical network architecture, a simple model has been considered, refer to Fig. 4. This two level hierarchical network consists of p backbone nodes. Each region is connected to one backbone and has q nodes. Moreover, fully meshed homogeneous traffic of granularity F between all regional nodes is assumed (i.e. $p \times q$ nodes in total). The result is backbone traffic of $q \times q \times F$ from each backbone node p to each other backbone node. In addition, we consider a switching granularity G of the backbone and a single channel that carries the traffic belonging to a "region-to-region" connection. For an optimal filling based on these assumptions, the switching bandwidth of the backbone is

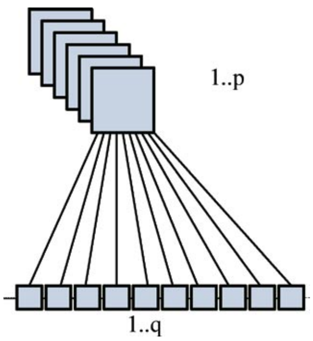
$$G = q \cdot q \cdot F \; ,$$

or, in other words, the ratio of the switching granularities is

$$\frac{G}{F} = q \cdot q \; .$$

In realistic networks the number of regional nodes per backbone node is about q=7…12 which means that the granularity ratio should be in the range between 49 and 144. Although the model and the estimation is rather simple, the result seems to be realistic. In "classical" SDH networks the ratio between VC-4 and VC-12 is 64, whereas in OTN networks, the ratio between ODU3 and ODU1 is only 16. Therefore, looking to the circuit switched transport part of a network, it can be concluded that a future hierarchical transport network should be a combination of VC-4 and OTN switching. It has to be noted that a final conclusion also has to consider the packet/frame based network layers, which could change the requirements for switching in the circuit switched layers.

Fig. 4:
Simple network model



3.3 Interoperability with SDH and Mapping Options

SDH is the appropriate technology for switching granularities of 150 Mbps (VC-4) and 2 Mbps (VC-12), and new SDH solutions can cross-connect concatenated containers of VC-4 (either contiguously concatenated or virtually concatenated ones).

As already shown in chapters 3.2 and 3.1, a universal architecture of future transport networks will probably consist of a combination of a VC-4 layer and OTN. Unfortunately, the current situation of the standardization is not totally clear, and there are several options for the functional distribution of cross-connecting functionalities, which are summarized in Fig. 5.

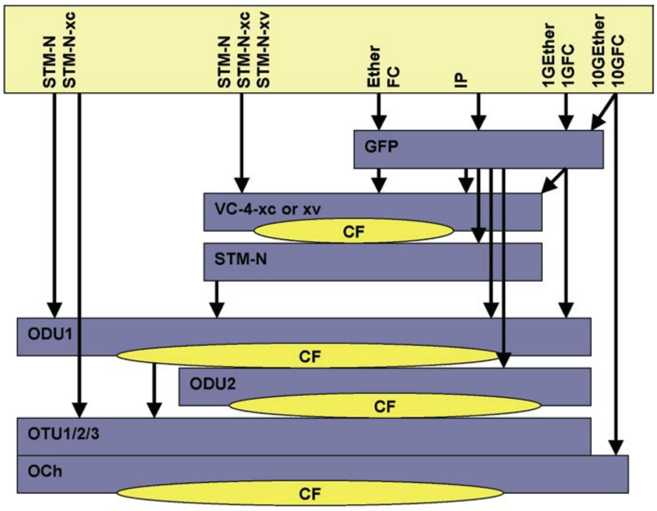


Fig. 5:
Options of cross-connection and functional distribution in a combined SDH-OTN architecture

In order to achieve a better interoperability between systems delivered by different system vendors and to achieve simple interoperability between different operator domains, it is desirable to reduce the variety of the options shown in Fig. 5. The reduction of options should have the following targets:

- specify only one solution for the transport of all kinds of Ethernet and FC formats
- avoid duplication of cross-connecting functionalities at optical channel level and at ODU level
- guarantee a good monitoring of broadband leased lines (STM and ODU leased lines)
- use the advantages of optical bypassing (avoidance of O/E/O)

Concerning optical channel data rates, 10 Gbps seems to be an appropriate bandwidth because it is relatively easy to handle with respect to PMD and high enough to switch broadband leased line services. Moreover, 10 Gbps is a realistic value for pure optical configuration (optical ADM, cross connects etc), which is important for the avoidances of costly O/E/O transponders. If there is no additional TDM between the connection function at the ODU layer and the connection function at the OCh-layer, the network function of both is compatible. There only remains a difference with respect to the monitoring functions. Unfortunately, these are vendor specific and incompatible at the OCh level.

3.4 Multi Channel Capability

For the first time the ITU-T has fully specified a multi-channel interface (Recommendation G.709 for frames and formats, Recommendation G.959.1 for physical aspects). The multi-channel interface is defined as an intra-office interface and is capable of the transport of 16 channels of OTU1, OTU2, or OTU3, respectively. The advantage of this kind of interface is quite obvious. Currently, the central offices are overloaded by optical fibre patch-cords carrying one single channel each. By introducing optical multi-channel interfaces, the number of patch-cords and the number or connectors can be reduced by the factor of 16, which will simplify the intra-office connections and which will also increase the reliability. Therefore, the operational costs can be reduced. For example, large cross-connects can have about 256 2.5G Interfaces, and standard WDM systems have up to 120 channels. If one assumes a very large network node which terminates 4 WDM systems, the number of single-channel patch cords is more than 960. A simple application of multi-channel interfaces could reduce this number to about 60.

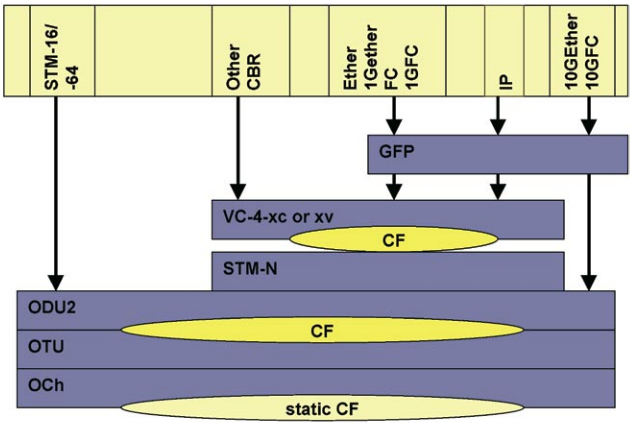
3.5 Conclusions

A summary of the assessment done in the previous chapters is given in Table 3, which shows advantages for SDH and OTN depending on the application. It is assumed, that characteristics of both technologies will be required in today's and future transport networks. Thus, an integrated transmission architecture based on OTN and SDH functionality is needed for highly interoperable and versatile transport networks. A OTN/SDH architecture combines advanced capabilities of OTN and the grooming and flexibility benefit of SDH.

OTN introduces several very relevant advantages: high capacity transport, seamless interaction between electrical and optical network domain, maintenance signalling and monitoring (incl. TCM) of the broadband channels, Forward Error Correction and good interoperability at single and multi channel level. On the other hand, at the OCh level there is no "digital" performance monitoring available comparable to the B-Bytes in SDH. This means that operators either can implement a quasi static configuration function at the OCh level in order to exploit optical by-passing or have to rely on the limited "analog" performance monitoring capabilities at the OCh-level (i.e. power monitoring, Q-factor measurements).

A proposal of a simplified architecture based on the assessment is shown in Fig. 6. Transparent STM-N (N = 16, 64) services are implemented via direct mapping into ODUk. Any kind of Ethernet and Fibre Channel signals >2.5 Gbps (including 10GbE WAN and 10GbE LAN PHY) are mapped into an ODUk using GFP. All other signals at lower bit rates are mapped into SDH entities, which additionally can be contiguously or virtually concatenated.

Fig. 6:
Simplified SDH/OTN architecture



	OTN	SDH
Monitoring and FEC		
Monitoring of path ≥ 2.5Gbps (connectivity, continuity, etc.)	++	-
Monitoring of path < 2.5Gbps	-	++
Standardized FEC function	++	+
TCM monitoring (nested domains)	++	-
Network Functions		
Integration of client formats	+	+
TDM - grooming / multiplexing capability	+	++
Effective usage of bandwidth	-	+
Interoperability at STM level	+	+
Interoperability at single OCh -level	++	-
Interoperability at multi-channel level	++	-
Switching granularity of signals ≥ 2.5 Gbps	++	-
Switching granularity of signals < 2.5 Gbps	-	++
Product availability	+	++
Port density of client network elements / intra-office cabling	++	-
End-to-end transparency	++	+
Protection & Restoration	+	++
Interfaces (interoperability)	IrDI	IrDI, IaDI
Synchronization	++	-
Scalability	++	-

Table 3: Assessment of OTN and SDH

4. OTN – Applications

Similar to the evolution from PDH to SDH, OTN extends the capability of SDH by providing additional network layers at bit rates of 2.5 Gbps, 10 Gbps and 40 Gbps, and also by adding functionality e.g. enhanced TCM and out-band FEC. Transport systems with those coarse granularities are addressing bandwidth needs of core transport networks but could also extend to the end customer in case of high capacity bandwidth services being required (e.g. GbE, 10GbE, STM-16, -64).

OTN provide high capacity interconnections required for an operator's major service platforms such as SDH, IP/MPLS, Ethernet and ATM, and it will also be the production platform for high bandwidth services requested by major corporate customers or other carriers.

From an application point of view, OTN needs to be seen as a platform to achieve two major objectives:

- providing transport services which can not be provided with existing technology, such as transparent SDH services
- improve network functionality by features like common management plane for optical and electrical network layers, advanced resiliency mechanisms, FEC, multi-level TCM and GFP mapping

The following paragraphs will outline the major applications of OTN and will also highlight specific functional advantages.

4.1 Interconnecting SDH Domains

OTN can be applied in core transport networks to interconnect SDH islands which belong to the same operator. The OTN edge network elements will be equipped with SDH cards not terminating the SDH multiplex and regenerator section overhead, but mapping the complete STM-N into ODU1/ODU2 frames. This way of operating the network does allow to monitor the connection between the SDH edge and OTN edge with SDH management functions and allows for a seamless alarm suppression between SDH and OTN.

4.2 Transparent SDH transport services

Even major operators do not have a global coverage, which allows them to reach any point of their network with own infrastructure. Leasing bandwidth from a carrier's carrier is a simple way to reach remote networks which do not have a connection to the main network. As important management information is transported in the section overhead, such connections should not just provide VC-4 connectivity but should also transparently transport the SDH overhead.

This can be achieved by mapping the complete SDH signal into an ODU frame. In order to supervise the quality of the client signal, non-intrusive monitoring can be applied utilizing specific characteristics of the SDH signal (e.g. B1 bytes).

4.3 Constant bit rate (CBR) services

There are client signals consisting of 2.5 Gbps bit streams without an SDH frame structure. Such signals previously required a single wavelength of a WDM transport system. This still might be an efficient way of service delivery if distances are short. However, if such services need to be transported over long distances, it is a quite expensive option to use a dedicated wavelength, as the service needs to be configured manually and can not be electrically multiplexed. If the WDM system supported 10G transport, the optical channel would only be utilized at 2.5 Gbps.

There is a standardized way of mapping CBR services into OPU/ODUs allowing not only to transport transparently but also to multiplex such data streams, e.g. by multiplexing of 4 ODU1 into an ODU2 or 4 ODU2 into ODU3, hence to increase resource utilization.

It should be noted that there is also the option of directly mapping into optical channels (OCh). This, however, will only be used if there are no requirements for more than basic OAM functionality.

4.4 Optical transport module (OTM) transport

In a multi-operator, multi-vendor scenario, services do not need to be terminated and de-mapped from the ODU at the edge of one domain but can be directly connected by OTM interfaces. As some of the OTN specific overhead is transported end-to-end and some can be used within segments of the connection, there are further means to manage and monitor such services on a per network domain basis. OTM interfaces are not just specified between the client and the transport network but also between the OTN switches and the DWDM transport system, which allows for standard compliant interfacing between TDM core switching and DWDM transport.

4.5 Data Transport Services

Provisioning transparent 10 Gigabit Ethernet services is evolving as a key requirement for telecom carriers. Looking at the technical task at hand, it may be useful to consider a) what would be – or would have been – a desirable solution originally, b) what is already evolving in the market segment and c) what desirable solutions can still be established from here.

4.5.1 Original situation

10 Gigabit Ethernet has been standardized in two basic physical implementations – the 10GBASE-R (LAN PHY) and 10GBASE-W (WAN PHY) versions. While LAN PHY implementations operate at 10.3125 Gbps, the WAN PHY is reduced to 9.54 Gbps. The WAN PHY was standardized at this rate to allow direct connection to SDH based networks at the STM-64 level. However, the different clocking concepts and jitter specifications of SDH and Ethernet still require to interpose an adaptation device at the hardware interface. In principle, the data rate of the 10GbE WAN PHY would allow to map this type of client directly into OTN as a STM-64c signal.

It has been outlined above that GFP is a very useful standard solution for mapping various clients into OTN. This is just as correct for 10GbE client signals. As only the frame-mapped GFP standard is applicable to 10GbE clients, bit transparency is not an option for this type of service; only MAC frame transparency can be maintained.

Summarizing, there would have been two key options originally for offering transparent 10GbE services over OTU2:

- 10GBASE-W direct mapped into OTU2 as STM-64c
- 10GBASE-R mapped into GFP and into OTU2

However, neither of these options really seem to be appearing in the market segment in volume.

4.5.2 Current situation in the market segment 2H 2005

For various reasons – comparative cost may be among them – 10GbE LAN PHY implementations are outweighing 10GbE WAN PHY implementations by far. Hence, the market segment requirement for transparent 10GbE transport is typically for 10GbE LAN, not WAN, transport. This makes it a largely useless fact that 10GbE WAN can be easily mapped into SDH and further into OTN.

The question at hand now really is – how can the 10GbE LAN PHY rate of 10.3125 Gbps be mapped into OTN, while still offering a reliable service with maximum transparency.

As the 10GbE LAN PHY client signal does not fit the OPU2 payload container, an adaptation function needs to be inserted. The adaptation can occur either in the OTN or in the Ethernet domain.

Hardware implementations seen so far are following various paths. Let us outline a few selected options here:

- Direct mapping of 10GBASE-R into an overclocked OTN: to compensate for the rate mismatch between 10GbE LAN PHY and the OPU2 payload, the overall OTU2 data rate can be raised from the standard 10.71 Gbps to 11.1 Gbps. This increases the OTN payload rate to fit the 10GbE LAN PHY client. Obviously, interoperability issues will arise and the option for upwards aggregation into OTU3 is lost. On the positive side, this option offers real bit transparency of 10GbE LAN client signals. Products which employ a direct mapping of 10GBASE-R signals into an overclocked OTN are commercially available.

- GFP mapping: as outlined above, GFP-F mapping of 10GbE LAN or -WAN clients into OTU2 is possible. Note that while in hierarchical diagrams the GFP mapping function may look like a standard building block, in reality it is still a separate piece of hardware for each type of client signal. So when compared to direct mapping options, GPF-F mapping adds an extra mapping layer without adding particular benefit.

- Direct mapping into OTN with optional flow control: here, the rate mismatch between 10GbE LAN and the OPU2 payload is compensated in the Ethernet domain. Depending on detail implementation, there will be some mechanism to generate flow control requests that allow a collision free rate adaptation. Potential compatibility issues are shifted to the Ethernet domain. In most real environments, the 3% reduction of the maximum Ethernet data rate should not become visible, as Ethernet channels are usually not filled to 97% – the threshold where it becomes necessary to activate the flow control mechanism.

At the moment, only the GFP-F based mapping option is currently standardized. However, in the first half of 2005, the ITU-T SG15 has initiated communication with IEEE 802.3 on the topic of standardizing another option for 10GbE-to-OTU2 mapping, but so far this has not yielded any documented progress.

4.5.3 Mid- to long-term solution

For obvious reasons, it is highly desirable to arrive at a single accepted solution for the mapping of 10GbE client signals into OTU2. The current situation, as outlined above, leaves us with doubts if this will ever happen. Some investment has been made already in more than one competing and mutually incompatible solution. A shift towards a single winner among these or other mapping schemes may only be determined by looking at volume hardware deployments in about two to four years from now. By then, carriers may have aligned on a common solution for interoperability.

Even though the “overclocked OTN” option has been implemented first and also is the only one so far to offer bit transparent services, it will likely not result as the long-term solution. The blocked upgrade path to the 40 Gbps class OTU3 signal is too much of a penalty for any large carrier to accept in the long term.

A further approach for a standard compliant mapping of a 10G LAN PHY into an OPU2 is based on the alignment of the bit rate of the LAN PHY interface with the capacity of the OTN 10 Gbps layer. This can be achieved by defining an additional line rate for a 10G LAN PHY at approximately 9.9 Gbps. The ITU Study Group 15 has sent to the IEEE a proposal based on the above.

This means that the market segment will most likely make its decision between GFP and direct mapping options. At least today, end-customer interest seems to dictate that maximum transparency is a feature to watch out for. While GFP-F is an attractive unified mapping scheme for most cases of data transport, it offers no added value for the special case of 10GbE-to-OTU2 mapping. As GFP-F only offers MAC frame transparency (with the frame preamble stripped), this leaves the direct mapping option as the most attractive one. It offers the most efficient solution to the technical problem, while having the benefit of simple and interoperable implementation. Furthermore, this option offers the potential of integration into 10GbE router hardware as an attractive future outlook.

In any case, offering transparent 10 Gbps Ethernet services over OTU2 is clearly an important application that will see volume deployment relatively soon.

5. Evolutionary Scenarios

Network operators have the following major motivations to consider the introduction of OTN:

- the immediate requirement for transparency of high bit rate signals (e.g. STM-16, STM-64) between customer locations
- the requirement for transparency of transport signals (STM-16, STM-64) from other operators (carriers' carrier application)
- the long-term vision of building a new overlay core network with extended OAM capabilities, efficient multi-operator interworking, and reduced OPEX

The introduction of OTN-capable networks therefore can be expected following different approaches:

5.1 Point-to-Point OTN Connections

High bit rate (≥2.5 Gbps) demands for transparent leased lines between customer premises or networks of other carriers can be covered by OTN NT (Network Termination) equipment which maps these demands into the appropriate OTN entity, e.g. STM-16-T (transparent STM-16) into ODU1 or STM-64-T into ODU2. This concept is depicted in the Fig. 7.

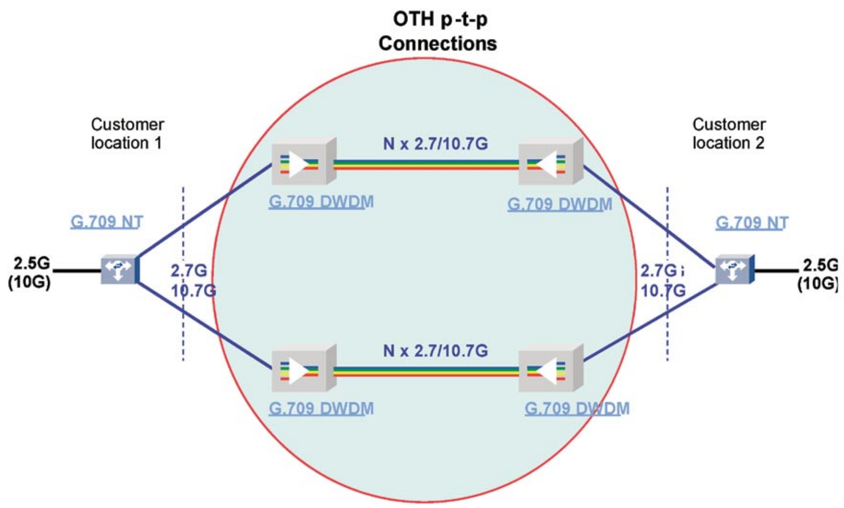


Fig. 7:
Point-to-point
OTH connections

It is shown in Fig. 7 that an OTN NT provides an (optional) protection function on the ODU level in order to meet the request for a high quality for high bit rate signals. The OTN NT (or G.709 NT, as referred to in the figure) can be seen as the key access element to OTN networks at customer locations, and will be used in all possible scenarios. On the network side, it will need 2/40/80 km non-complex interfaces (called OTM-0.m: single lambda, non-colored, no OSC) that will connect with G.709 capable WDM systems in the core nodes. Bypassing the metro network in this approach is very cost effective for operators if there is sufficient amount of fiber available. When the network grows and many more Gbps services are to be supported, or when no more fiber is available, OTN metro networks will be needed as well.

The OTN NT should be used for long-distance services together with OTN line systems allowing transparent point-to-point (WDM based) transport of ODUs (also called G.709 capable WDM). As the transport of the ODU signals is performed with dedicated OTN links and equipment sets, this approach sometimes is also referred to as the (OTN) “overlay model”.

The OTN overlay model can be complemented by – transparent – switching functionalities in the optical (WDM) domain by means of either all-optical OXCs (Optical Cross Connects) or ROADMs (Re-configurable OADMs). These devices transparently switch Optical Channels (OCh) or even (parts of) the OMS/OTS signals and do not require the implementation of electrical OTN (ODU) switch fabrics. This is also a migration path to a fully featured OTN network as described in section 5.4.

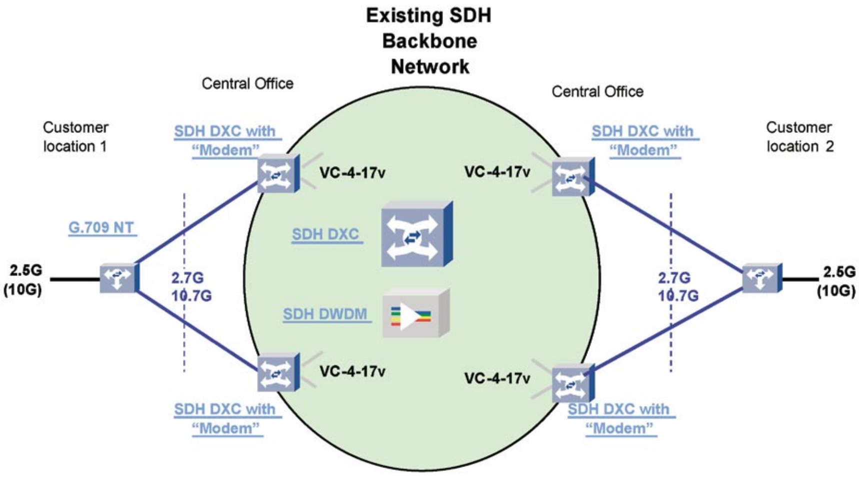
5.2 OTN Connections over SDH Networks

In networks with limited demand for OTN signals, it may be necessary and economically advisable to interconnect OTN NTs or OTN subnetwork islands via an intermediate SDH network which is in use already. This can be achieved by the introduction of “G.modem” as described in section 2.5, which allows the transport of ODUs via SDH networks. From an operator’s point of view, this allows for a smooth network evolution with minimal starting invest.

Besides the NT, only one new functionality, the “G.modem”, is required at the edge of the network. No further new functionality or other change within the network is required, i.e. current SDH NEs as well as current WDM and network management systems can further be utilized.

Currently this mode of operation is seen as a niche application, mostly applicable for existing SDH networks with a very small amount of STM-N transparency requirements. This scenario is shown in Fig. 8.

Fig. 8:
G.modem connection via SDH network

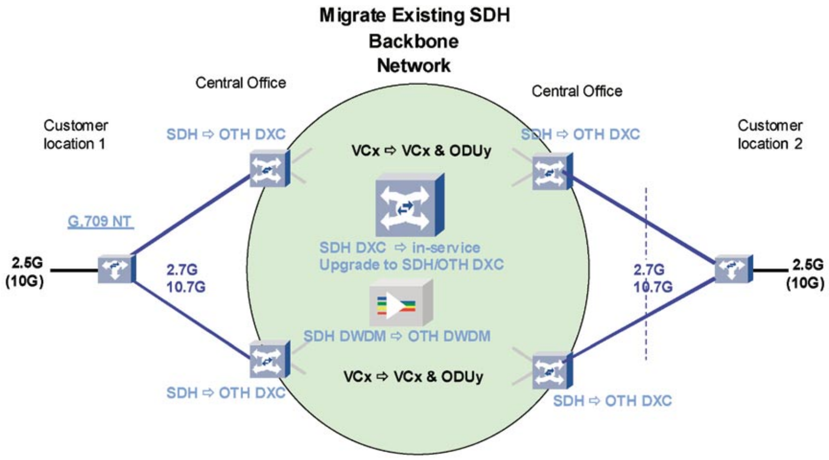


5.3 Migration from SDH to OTN Networks

Typically the demand for OTN services will grow over time. Some initial OTN links might be provided by transparent mapping of services into wavelengths as outlined in section 5.1 or by "G.modems". If the demand further increases such implementation of OTN services is not sufficiently efficient. A seamless migration from SDH and DWDM towards OTN needs to allow a high degree of re-use of the installed base but at the same time avoid inefficient use of resources.

Such a migration can be achieved by in-service upgrade of SDH and DWDM systems towards SDH/OTN capable multi-technology switches in combination with OTN-compliant DWDM transport systems. This however requires a cross-connect, which can be upgraded from SDH towards OTN and DWDM systems, which are OTN compliant. Such network elements are available today.

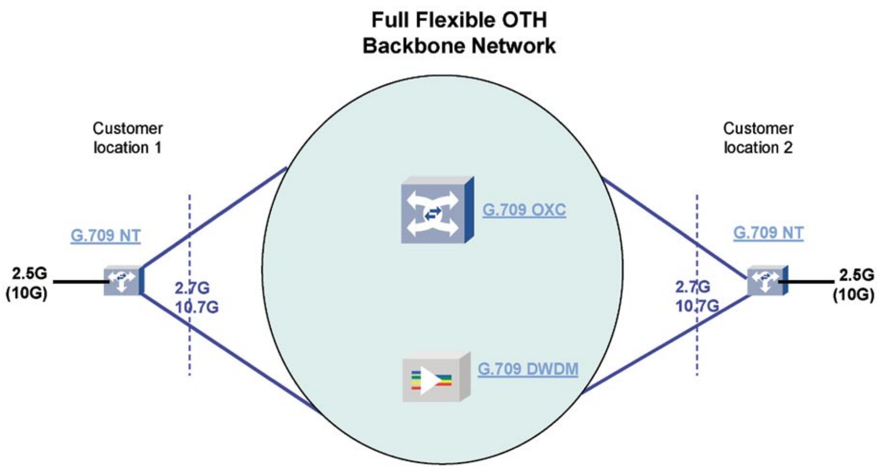
Fig. 9:
Migration from SDH to OTH Networks



5.4 OTN Connections over Full Flexible OTN Networks

The introduction of full OTN networking capabilities (OAM, client mapping, flexible connectivity, grooming, restoration) for ODUs realized by OTN cross-connects (in addition to the OTN NTs and WDM systems already shown in section 5.1) can be seen as the target solution a network will evolve to if the business environment allows for it. This may be the case, for example, with the growth of transparent services reaching an appropriate level, or with customer expectations on OAM which cannot be fulfilled by legacy systems. The fully featured OTN solution is shown in Fig. 10.

Fig. 10:
OTN connection over fully flexible OTH backbone



5.5 Comparison of Introductory Scenarios

For the introduction of an OTN network, where in the beginning the requested amount of relevant services is still moderate and not dynamic, a network operator has the choice between two introduction approaches: the “overlay approach” as described in section 5.1, or the “SDH approach” as shown in section 5.2. Both scenarios provide an end-to-end supervision of the ODU paths and a high availability due the protection function in the OTN NT.

A seamless migration from SDH to OTN is provided by an upgrade of the SDH network to OTN as outlined in chapter 5.3. This however requires network elements, which are able to run with a multi-technology switch core. Such networks are installed by operators which expect a growth of OTN services in the near future or already today provide such services.

The choice of the introductory approach should preferably be done with the view on the final network concept. If the installed base can not be upgraded to OTN, starting with G.modem and switching to a full OTN scenario later either leads to the necessity to replace all G.modem ports by new OTN ports (additional CAPEX), or to operate two separate networks for the same purpose simultaneously (additional OPEX). Consequently, the potential cost advantages of a G.modem solution will be more than compensated by these additional costs.

Another sensible approach for those network operators who finally want to implement a fully featured OTN network (as depicted in section 5.4) but can not upgrade existing SDH network elements is to start with the “OTN WDM approach” (as per section 5.1) and to install the OTN OXCs as flexibility points of the OTN network in the next step.

Only if the network operator already knows from the beginning that OTN connections will be used for a restricted number of services only and a significant growth is not expected, the G.modem approach (section 5.2) allows for a smooth integration into an existing SDH environment with low initial CAPEX and low OPEX.

6. Summary

There is a growing demand for high-capacity, transparent bandwidth services, which are required to interconnect operator domains, to provide connectivity within storage area networks or to connect business customers with centralised server farms. Those services can not be provided by legacy SDH and DWDM in an efficient way.

This was the reason for ITU to develop a transport network beyond SDH, which extends the container concept of SDH towards Mulit-Gbit/s transport and also provides a common network architecture for the electrical and optical domain of transport networks. The OTN standards are based on the proven management and maintenance concept of SDH, but extend it towards the requirements of multi-operator networks and data-centric transport.

OTN currently defines three hierarchy levels with 2.7 Gbps, 10.7 Gbps, and 43 Gbps, respectively. It also defines certain layers where various monitoring functions and advanced functionalities like FEC are available. In particular, OTN provides monitoring functions that allow transparent transport over different vendor and network domains, including (end-to-end) Tandem Connection Monitoring which is supported for nested, overlapping, and cascaded domains. Transitions between the hierarchy levels are obtained by multiplexing 4 lower-level signals into the next higher level. Payload mapping can either be direct (e.g. for SDH/SONET 2.5 Gbps and 10 Gbps signals), or via GFP.

An analysis of bandwidth service requirements revealed, that efficient transport networks will consist of a combination of SDH (VC-4 level with both, virtual and contiguous concatenation) and OTN (at least 2.7G and 10.7G, since these are mature transport rates). Without SDH, poor wavelength utilization due to the coarse granularity might occur. In addition, SDH/SONET can add powerful protection mechanisms.

OTN introduction strategies will depend on the specific network situation of an operator and the envisioned service portfolio. Different roll-out scenarios have been compared in this document. There is the possibility to provide OTN over SDH (i.e. OTN migration) by “G.modem” (ITU-T G.707 §10.7). If fully-featured OTN is required, a seamless extension of the existing infrastructure allows to grow networks from SDH/DWDM to OTN.

OTN networks will be composed of various equipment types such as

- OTN gateways at customer premises (OTN NTs) providing the client (e.g. SDH) to server (OTN) adaptation

- OTN cross-connects in central offices providing also the gateway functionality, and in addition being the fully flexible switching facility, allowing real networking

- OTN WDM systems providing the long-distance transport of OTN entities and the OTN overhead related OAM functionalities

OTN-compliant DWDM transport is applied in many operator networks today. With ODU switching products becoming increasingly available from several manufacturers, this technology will soon augment existing SDH networks.

When introducing OTN technology operators will also consider the advantages of advanced resilience mechanisms, e.g. restoration based on distributed routing and/or signaling protocols. Such Automatically Switched Transport Network (ASTN) technology is currently developed by other ITU working groups [9].

References

[1] ITU-T Rec. G.872, "Architecture of Optical Transport Networks", 2001 + Amendment 1, 2003.

[2] ITU-T Rec. G.709, "Network Node Interface for the Optical Transport Network (OTN)," 2001.

[3] ITU-T Draft Rec. G.7041, "Generic Framing Procedure (GFP)," pre-published 08/2005.

[4] P. Bonenfant and A. Rodriguez-Moral, Generic Framing Procedure (GFP): The Catalyst for Efficient Data over Transport IEEE Communications Magazine, May 2002 pp 72-79.

[5] P. Bonenfant and A. Rodriguez-Moral, "Framing Techniques for IP over Fiber," IEEE Network, Jul./Aug. 2001, pp. 12–18.

[6] ITU-T Rec. G.707, "Network Node Interface for the Synchronous Digital Hierarchy (SDH)," 2000.

[7] ITU-T Draft Rec. G.7042, "Link Capacity Adjustment Scheme (LCAS) for Virtual Concatenated Signals," 2001.

[8] E. Mannie et al., Ed., "Generalized Multi-Protocol Label Switching (GMPLS) Architecture," IETF draft, <draft-ietfccamp-gmpls-architecture>, Mar. 2002, work in progress.

[9] ITU-T Rec. G.8080/Y.1304: "Architecture Of The Automatically Switched Optical Network", Nov. 2001, Amendment 1 March 2003, Amendment 2 February 2005.

Abbreviations

3R	Reamplification, Reshaping & Retiming
ATM	Asynchronous Transfer Mode
AIS	Alarm Indication Signal
APS	Automatic Protection Switching
ASON	Automatically Switched Optical Networks
BDI	Backward Defect Indication
BEI	Backward Error Indication
BI	Backward Indication
BIP	Bit Interleaved Parity
FDI	Forward Defect Indication
FEC	Forward Error Correction
GFP	Generic Framing Procedure
GMPLS	Generalized Multiprotocol Label Switching
IaDI	Intra-Domain Interface
IAE	Incoming Alignment Error
IrDI	Inter-Domain Interface
LOS	Loss of Signal
OCC	Optical Channel Carrier
OCCo	Optical Channel Carrier – overhead
OCCp	Optical Channel Carrier – payload
OCh	Optical channel
ODU	Optical Data Unit

ODUk	Optical Channel Data Unit-k
OH	Overhead
OMS	Optical Multiplex Section
OMS-OH	Optical Multiplex Section Overhead
OMU	Optical Multiplex Unit
ONNI	Optical Network Node Interface
OOS	OTM Overhead Signal
OPS0	OTM0 Physical Section
OPU	Optical Payload Unit
OPUk	Optical Channel Payload Unit-k
OSC	Optical Supervisory Channel
OTH	Optical Transport Hierarchy
OTM	Optical Transport Module
OTN	Optical Transport Network
OTS	Optical Transmission Section
OTS-OH	Optical Transmission Section Overhead
OTU	Optical Transport Unit
OTUk	Optical Channel Transport Unit-k
PCC	Protection Communication Channel
PLD	Payload
PM	Path Monitoring
PMI	Payload Missing Indication
PMOH	Path Monitoring Overhead

SDH	Synchronous Digital Hierarchy
SM	Section Monitoring
SMOH	Section Monitoring Overhead
TCM	Tandem Connection Monitoring

VDE

VERBAND DER ELEKTROTECHNIK
ELEKTRONIK INFORMATIONSTECHNIK e.V.
Stresemannallee 15
60596 Frankfurt am Main

Telefon +49 69 6308-0
Telefax +49 69 6312925
www.vde.com
service@vde.com