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The ultimate Solution to transport Multiple Clients over Optical Networks?

Optical networks today are able to transport an astounding volume of data and voice traffic over one single fibre. At the same time, this information is framed in a growing number of different formats, such as SDH, GbE, ATM, FR or IP. It would be advantageous to transmit all kinds of different formats using only one single framing to provide client transparency.

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ATM, FR or IP. It would be advantageous to transmit all kinds of different formats using only one single framing to provide client transparency.
The Digital Wrapper (DW) is a framing format proposed for the transmission of any digital client signal on an optical channel. It is also seen as the best technique to transport the management information of the optical channel. In addition, the inclusion of some form of error correction will relax limitations of the optical transmission. It will allow longer spans between electronic regenerators. The development of a standard for the DW is currently under discussion in the ITU-T SG15 and SG13. The status of standardisation and some possible DW applications are presented here. Swisscom is following the elaboration of this new concept and also participating to it through Project ONE (Optical Networking) in the frame of the CT Exploration Program EP9 and through EURESCOM Project P918 IP over WDM.
The main application area of the DW is the optical network using Wavelength Division Multiplexing (WDM), where every optical channel corresponds to one specific wavelength. The alternatives to the digital wrapper, namely the SDH frame, pilot tones, spread spectrum and the optical supervisory channel, have several drawbacks. Either they do not carry enough management information and cannot perform error correction, or they transport the overhead on a separated channel leading to additional multiplexing complications. Due to its advantages, the DW is now being developed by several suppliers. Equipment which implements some form of a DW have been announced for 2000. As long as the standards are not finalised, proprietary solutions will be realised.

Introduction

In recent years, we assisted to a real telecommunication revolution. New services such as mobile telephony, internet and multimedia widely spread off and provoked an explosion of the bandwidth demand. In the next decade bandwidth growth will even accelerate. In this fast moving telecommunication world, the network has to provide a huge bandwidth for the transport of a multitude of different client services.
The high capacity requirements of the backbone networks can be fulfilled by the Wavelength Division Multiplexing (WDM) technology. Up to 120 wavelength channels can be transmitted over one single optical fiber with commercially available WDM systems. Another way to increase the capacity is to migrate from 2,5 Gbit/s systems to 10 Gbit/s systems. Capacity close to 500 times that of a 2,5 Gbit/s single fiber channel can be achieved by combining fast TDM with Dense WDM (DWDM) technology. However, even if the bandwidth problem is thought to be solved by the use of WDM and fast TDM technologies, the network operators are still facing important problems. These problems can be summed up by the three following questions:
- How to manage such a huge bandwidth?
- What is the best architecture for the transport of multi-clients in a layered network?
- How to control the degradation of the signal quality resulting from higher bitrate and higher number of wavelengths?

These topics are studied in Corporate Technology (CT) in Project ONE of the Exploration Program EP9 and in collaboration within the EURESCOM Project P918 (IP over WDM). The ITU-T is working on these topics in the questions 19/SG13 and 11/SG15. Both questions treat the problem of the management of Optical Transport Networks (OTN) which also has to take into account the flexibility to carry multi-clients. Up to now, only the functional architecture of the OTN [1] and the WDM wavelength grid [2] are

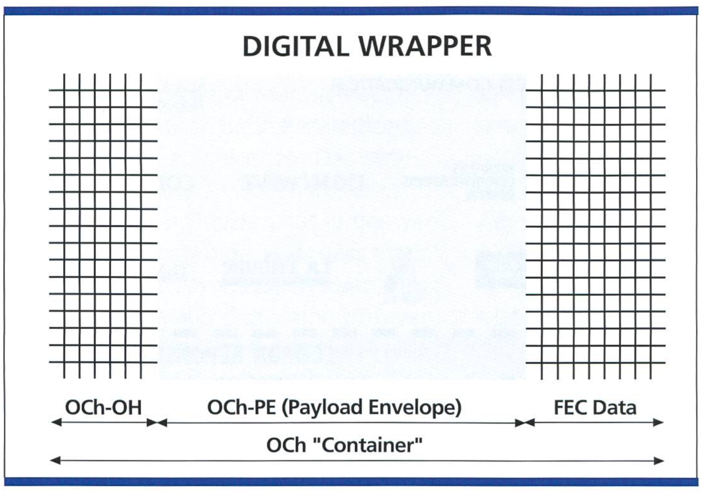

Fig. 1. Schematic representation of the OCh container (Digital Wrapper)

	OCH-OH	Payload				Check Bytes					
Col.1	**Col 2**	•	•	•	**Col. 239**	**Col. 240**	•	•	•	•	**Col. 255**
Subframe 1	1	17	•	•	•	3809	3825	•	•	•	4065
Subframe 2	2	18	•	•	•	3810	3826	•	•	•	4066
Subframe 3	3	19	•	•	•	3811	3827	•	•	•	4067
•	•	•	•	•	•	•	•	•	•	•	•
•	•	•	•	•	•	•	•	•	•	•	•
•	•	•	•	•	•	•	•	•	•	•	•
Subframe 16	16	32	•	•	•	3824	3840	•	•	•	4080

Fig. 2. OCh Basic Frame Structure (1 column for OCh-OH, 238 for payload and 16 for FEC).

standardised. The OTN management is still an open question. One critical issue for the OTN management is the choice of the physical method to transport the OTN overhead information. Five possibilities may be considered: pilot tones, spread spectrum, Optical Supervisory Channel (OSC), in-frame techniques (SDH based) and Digital Wrapper (DW). The ITU-T is investigating the advantages and drawbacks of the five methods. No definitive choice has been done yet, but the DW is widely considered to be the most promising technique.

In the following, we compare the five methods and inform about the DW technique, the status of the standardisation and the supplier's view. We also present some possible applications.

Motivations for a Digital Wrapper

Firstly, the transmission capacity over a single fibre is approaching the Tbit/s, what makes the management of the OTN very critical. Secondly, a multitude of services has to be realised over the network and different multi-client network layers must be supported by the OTN. A third important feature of the OTN management deals with the signal quality control of the long haul and high bitrate optical transmissions. The proper performance of the whole chain of optical elements must be ensured and the Bit Error Ratio (BER) must remain acceptable.

Comparisons between different techniques for realising these objectives are being done in the EURESCOM Project P918 [3]. Each method has its advantages and drawbacks and can be used in particular cases.

- *The pilot tone is a simple and cheap method: it consists of a low frequency modulation of each wavelength channel. Each channel is identified by its specific modulation frequency. However, the information is limited to the wavelength inventory and the channel power level. Due to interference and cross-talk effects, no more than 16 channels can be handled [4, 5]. An important advantage of the pilot tone is the ability to monitor the individual channels anywhere along their trail, without WDM demultiplexing.*
- *The spread spectrum technique uses a digital amplitude modulation of the client signal and code division multiplexing for the overhead information. The implementation of the spread spectrum technology does not require a strong investment in hardware components. Unfortunately, the overhead is limited to about several kbit/s and noise is added to the client signal.*
- *The "In-frame" technique uses the client layer, for example SDH, to transport the optical channel information. It may be the cheapest method, because it is based on the existing infrastructure. The drawback is its client dependency and its strongly limited capacity for the OTN overhead information. The low number of free SDH-OH bits cannot provide enough information. Therefore, advanced Forward Error Correction (FEC) is not possible and OTN performance management is very limited. FEC uses some bits added to the client load for correcting errors generated during transmission.*
- One possibility to increase the bandwidth for overhead transmission is to use an Optical Supervisory Channel (OSC) on a separate wavelength. Several Gbit/s overhead information can be transmitted through the OSC and this technology does not degrade the signal quality. However, this method uses a stand-alone channel and multiplexing is required to follow each individual Optical Channel. The OSC is optimal to support the management of the Optical Transmission Section (OTS)[1] and the Optical Multiplex Section (OMS)[2]. In the case of the Optical Channel (OCh)[3], the OSC is only efficient for point to point WDM systems, where the end points are identical for OMS and OCh. Another drawback is the difficulty to synchronise the stand-alone OSC channel and the optical channels, especially in a complex WDM network.
- These disadvantages disappear if the OTN overhead and the client payload are encapsulated together in a digital frame. This encapsulation is performed by the Digital Wrapper (DW). The DW allows the transport of the required OCh overhead information in an embedded channel. Control of the BER is possible and, unlike for other techniques, FEC and tandem connection monitoring can be easily integrated. Furthermore, the DW does not degrade the client signal and is able to transport any kind of digital client. Compared to other techniques, the DW is the only method that provides the required overhead information, error correction and client transparency without degrading the client signal. Its only drawback is its cost. A new sub-layer must be implemented, which means that new hardware components at each optical channel termination point are needed. However, the overall advantages of the DW make it a cost-efficient solution.

[1] The OTS is the optical section ended by two optical elements such as emitter, amplifier, (de-)multiplexer or receiver.
[2] The OMS is the optical section that is delimited by two (de-)multiplexers.
[3] The OCh corresponds to the wavelength channel section that begins at the transmitter and passes through amplifiers and (de-)multiplexers, ending at the receiver. A schematics of the three sections is presented in the fifth paragraph.

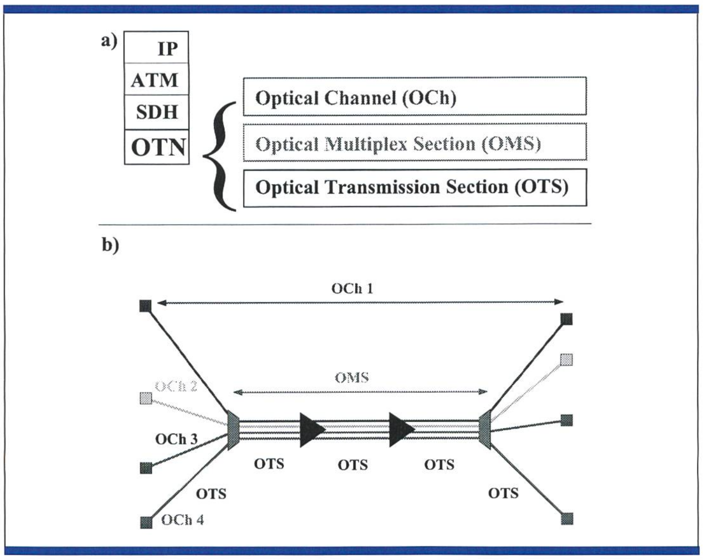

Fig. 3a. Schematics of a network with IP/ATM/SDH over the OTN, showing the ITU-T three layer model for the OTN.

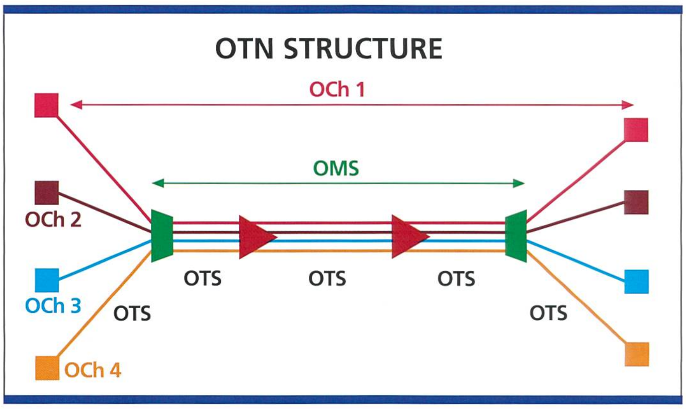

Fig. 3b. OTN structure for a WDM point to point connection. The OCh connects the transmitter to the receiver (squares) by using a specific wavelength channel (represented by a specific colour). The OMS corresponds to the multi-wavelength link between two (de)multiplexers (drawn in green). The OTS is the fiber link between two optical elements such as transmitters, receivers, (de)multiplexers or optical amplifiers (drawn in black).

A sum up of the comparison of the different techniques for the transport of the optical channel management information is given in table 1.

Specification of the Digital Wrapper

The first proposal for a framing structure of the DW was given by Lucent in an ITU-T contribution [6]. The frame structure proposed is based on the framing described in the ITU-T recommendation G.975. This recommendation specifies a frame structure for the transport of a STM-16 payload for submarine systems and which includes FEC. The formatting could be extended to STM-64 or to any digital client with a constant bit rate. By using 7,5% (15/14) of the frame for FEC, an improvement of 5 to 7 dB for the optical signal to noise ratio is achieved. This means that FEC allows an increased length between electrical 3R-regenerators. The line rate for STM-16/-64 clients would increase to 2,66606/10,66423 Gbit/s with this coding scheme.

The components realising the functionality of the DW will be part of the transponder and of the electronic 3R equipment. It may consist of one single integrated circuit.

Figure 1 shows a schematic representation of the proposed OCh container. The client signal floats within the OCh "Payload Envelope" (OCh-PE). The format of the OCh client signal is not constrained by the OCh container format. The client signal needs only to be a digital signal of constant bit-rate within the bandwidth of the 3R regenerator function. The OCh-PE can be viewed as a format independent, constant bit-rate channel. Unlike SDH, no pointers indicate the frame position of the client signal within the envelope. Note that although client-specific devices will be required for visibility of the client signal, new emerging client signal formats can be transported without any changes to the OTN, with the exception of points of client adaptation at the edges of the network.

Figure 2 shows the basic OCh frame or "container" structure. Each cell represents one byte. The numbers in the cells indicate the order of transmission of each byte. The check bytes correspond to the bytes used for FEC. Forward error correction is still a controversial issue in ITU-T, because of a lack of knowledge about the optimal correction algorithm for terrestrial communications. Therefore, the precise definition of the FEC bytes is for further study within ITU-T and the proposal shown in fig. 2 will be re-worked. Furthermore, as the use of FEC creates delay and as it is not necessary at each DW location, the use of a FEC must remain optional.

As visible in fig. 2, only 16 bytes are allocated for the OCh-OH. For a better flexibility for assigning overhead functions, it is proposed to use a multiframe with 4 frames. A superframe consisting of 4 single frames results in 64 bytes for the overhead that can be allocated between framing, parity check bytes, and miscellaneous OCh-OH functions.

Two functions of the overhead, framing and performance verification via parity checking, have been considered into detail [4]. One column of the OCh-OH multiframe would be allocated to the framing, and another one to the end-to-end performance monitoring capability.

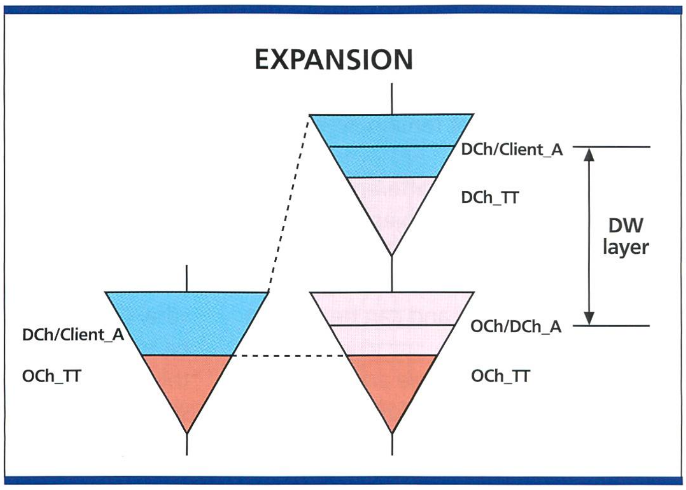

Fig. 4. Expansion of the OCh layer adaptation function. The DW layer corresponds to the DCh with its trail termination and its adaptation to the OCh and client layers.

Referenzen

[1] ITU-T Recommendation G.872

[2] ITU-T Recommendation G.692

[3] EURESCOM Project P918 "Integration of IP over optical networks: Networking and Management"

[4] EURESCOM Project P918, OG42-02a.doc "Capacity requirements of the OAM signalling"

[5] EURESCOM Project P918, IT42-02a.doc "Analysis of techniques for physical transmission of OTN overhead information"

[6] ITU-T SG 15, Geneva meeting, June–July 99, D. 498

[7] ITU-T SG 15, Geneva meeting, June–July 99, D. 500

In Ref. [7] a precise description of the byte allocation for the other overhead functions is given. The different overhead functions proposed are: the section trace, the section data communication, the section growth, the tandem connection monitoring, the OCh path overhead and the OCh path functions. It should be added that the DW is a solution for the management of the OCh. The OMS and the OTS cannot be managed by the information contained in the DW, and an OSC is still required for their management.

Open Issues

The standard for the DW is not yet finished and there is no commercial product on the market. The reason for this is that some controversial issues still have to be resolved, such as:

- Instead of defining a completely new framing, one could use the SDH frame with some redefined OH bytes (NTT proposal). For SDH clients, there would be no need to replace line terminal equipment or to re-design the optical modulators, receivers and repeaters.
- The optimum coding scheme could be different for terrestrial optical networks than for submarine ones, due to different cross talk and degradation effects. The FEC for submarine systems (G.975) was designed for long haul point-to-point transmission with a chain of optical amplifiers. Terrestrial networks are quite different in that they have shorter spans and more optical elements. Therefore deterministic optical cross-talk may dominate the random noise originating from optical amplifiers and non-linear effects.
- Should the FEC be optional or mandatory? This is mainly an economic question. Besides the cost for the circuit itself, the power consumption for the FEC could be one issue and the delay for decoding/coding an other one.
- The content of the OCh-OH (based on G.872) is not yet defined for the DW. Additional information for OA&M of the OMS section will be transmitted in an OSC at a specific wavelength.
- The line bit rates depend on the number of bytes reserved for OCh-OH and FEC.
- The structure of the multiframe, proposed to allow sufficient OCh-OH functions, is still for discussion.

Digital Wrapper and OTN functional Architecture

According to the functional modelling reported in ITU-T [1], the optical transport network (OTN) is composed of three optical layers shown in fig. 3a: the optical channel (OCh), the optical multiplex section (OMS) and the optical transmission section (OTS) layer. As illustrated in fig. 3b, the OTS corresponds to the fiber link between two optical elements such as amplifiers, (de-)multiplexers, transmitter and receiver. The OMS corresponds to the link between a WDM multiplexer and a (de-)multiplexer, and the OCh to one wavelength channel between the transmitter and receiver.

The DW corresponds to a new functionality at the termination points of the OCh, i.e. at transmitters and receivers. It integrates the control of management information, BER determination, and the FEC function. Therefore, additional hardware is required at the transmitters/receivers location (shown as squares in fig. 3b). These elements may be integrated together with electronic 3R repeaters or with transponders. Therefore the added cost may be minimised.

The integration of a DW in the OTN requires a fourth optical layer or a modification of the OCh definition. The EURESCOM Project P918 [3] proposes to maintain the ITU-T three-layer model and to integrate the digital wrapper layer within the optical channel layer. For a better understanding of this proposal, a short description of the functional architecture of a multilayer network is needed (fig. 4). The functions of a layer comprises the Connection, the Trail Termination (TT) and the Adaptation (A) to the client layer. The connection corresponds to the physical link between the two termination points. The TT-function performs the supervision of signal integrity of the layer and the A-function represents the conversion process between a server and a client layer. Therefore, the A-function partly belongs to the server and partly to the client layers. In fig. 4, the TT- and the A-functions are represented by triangles and trapezes, respectively. For the OCh, the A-function can be represented by the interface between the OCh and the clients, such as SDH, GbE or ATM.

As the DW is a sublayer between the OCh and its clients, it can be considered as part of the OCh/Client adaptation function. The EURESCOM P918 Project proposes to consider the DW as an expansion of the OCh layer adaptation function. This expansion is shown in fig. 4 with the DW represented by a layer called "Digital Channel" (DCh).

One advantage of integrating the DW in the OCh layer is that it remains in line with ITU-T G.872 [1]. Another advantage is the perfect correspondence with the role of the DW to support the OCh: the DW provides solutions to specific OCh problems, such as the transport of the OCh overhead information, the access to the BER and the FEC. However, the approach presents one drawback: the OTN and the OCh do not correspond to pure optical layers. With the DW, opto-electronic conversion is included in the OTN. However, due to the properties of the DW, this does not affect the protocol transparency of the OTN.

Vendors Position

Lucent announced products including the DW for the beginning of year 2000 (Lucent homepage). Marconi intends to deliver an interface including the DW in 2000. The cards will be upgraded later on, to a standard compliant version at the supplier's account. Nortel, Siemens, Alcatel, Ciena do not seem to have made up their choice yet. They are probably waiting for finalised standards. When suppliers are asked about the reason for a DW implementation, they generally answer: "What else do you propose to transport a multitude of clients and to realise advanced FEC?" They do not see real alternatives. The use of an

Technique Transparency	Client Layer Penalty	Client Signal Capacity	Transmission Correction	Forward Error	Cost	Remark
Pilot tones	Yes	Interference perturbation	Up to 1 kbit/s	No	Low	Low number of channels
Spread spectrum	Yes	Added noise	No kbit/s	No	Low	
"In-frame" (STM 16)	No	No	0,25% of channel bitrate	No	Very low	No additional hardware required
Optical supervisory channel	Yes	No	No Gbit/s	Difficult to integrate	Relatively high	Stand alone channel: – Multiplexing required – Difficulty of synchronization with the OCh
Digital Wrapper	Yes	No	7% of channel bitrate	Possible	Relatively high	OH and payload in the same frame. FEC, TCM etc. can be integrated

Techniques for the physical transport of the OCh management information, with their advantages and drawbacks.

OSC for the OCh is difficult to synchronize and to administrate. An "associated OCh-OH" such as the DW is much simpler. The main barrier for the DW is the installed base in SDH equipment. The migration path to new terminal equipment is not evident and could be expensive. What concerns the advanced FEC, it is proposed to include an FEC in the DW at any case, also for cases when FEC is not used. One single integrated circuit costs less than two specific circuits, one including FEC and the other not including FEC.

Conclusions

What will be the profit using the DW?

- Firstly, having the best solution for the transport of the OTN management information.
- Secondly, guaranteeing a high quality of signal by providing a tighter control of the optical path.
- Thirdly, getting longer spans and/or more wavelengths in the optical path, due to the FEC.
- A fourth important advantage of the DW is its ability to carry multi-clients. Therefore, it can be considered as the ideal candidate for the transport of multi-services over WDM.

It is important to carefully observe the standardisation progress of the digital wrapper and its alternatives. Through EURESCOM Project P918, Swisscom even has the chance to contribute to the standardisation. We must be aware of the specifications of the first commercial products. However, an introduction of equipment using the DW should be considered for standardised DW format only. Whether this is an approved ITU-T standard or a commercial de-facto one is of less importance. Standardised products may be expected in 1 to 3 years time. The definition of an advanced framing for the transport of multiple clients over WDM will open the field for networks with better manageability and better control of signal quality at lower overall cost. 8.3, 9.4

Jacques Robadey *studied Physics at the ETH Zürich and received his Physicist Diploma in 1991. He then worked on laser physics at the Institute of Micro- and Optoelectronics at the EPFL Lausanne. He received the Ph.D. degree for his work about the fabrication and characterisation of new types of complex coupled DFB lasers. Since 1999 he has been with Swisscom AG in Corporate Technology, where his activity focuses on the management of optical networks.*

Christian Zimmer *received the Physicist Diploma from the ETHZ in 1966. He then contributed to various research topics from optical communications to optical measurement equipment in R&D of Hasler/Ascom. After establishing a hybrid circuit production line he worked on laser welding for opto-electronic packaging. Having joined the R&D division of Swisscom AG in 1992, he is at present active in the applications of optical networking and WDM in the trunk and access network.*

Abbreviations

A	Adaptation
BER	Bit Error Ratio
DCh	Digital Channel
DW	Digital Wrapper
DWDM	Dense Wavelength Division Multiplexing
EURESCOM	European Institute for Research and Strategic Studies in Telecommunications
FEC	Forward Error Correction
FR	Frame Relay
GbE	Gigabit Ethernet
OA&M	Operation, Administration and Maintenance
OCh	Optical Channel
OH	Overhead
OMS	Optical Multiplex Section
ONE-Project	Optical Network Project
OSC	Optical Supervisory Channel
OTN	Optical Transport Network
OTS	Optical Transmission Section
PE	Payload Envelope
3R	Re-amplification + Re-shaping + Retiming
SDH	Synchronous Digital Hierarchy
STM-N	Synchronous Transport Module Level N
Tbit/s	Terabit per second
TCM	Tandem Connection Monitoring
TDM	Time Division Multiplexing
TT	Trail Termination
WDM	Wavelength Division Multiplexing