CHAPTER 1

INTRODUCTION TO OPTICAL TRANSPORT

This chapter covers the history of the development of SDH, SONET, and OTN. For consistency in the terminology used in this book I have included a list of conventions. This chapter ends with a list of all standards documents that are related to SDH, SONET, and OTN. Chapter 2 provides an overview of possible network topologies and introduces the functional modeling methodology used to describe the transport network. Chapter 3 describes the frame structures defined for use in the transport networks. In Chapter 4 the operation of SDH, SONET, and OTN is explained using the functional model. Per function it is described how the information in the associated frame structure is processed. The evolution of a pure voice-centered transport network towards a packet-based transport network (PTN) required the definition of a functional model of the latter as well. The model of the PTN is provided in Chapter 5. Processes that are generic and which can be used in different layers are described in separate chapters; the frequency justification processes in Chapter 6, the protection mechanisms in Chapter 7, and the mapping methodologies in Chapter 8. Chapter 9 describes how more flexibility in bandwidth can be achieved using existing frame structures. To conclude, Chapter 10 contains a reference table that provides an overview of the processing of the information in the SDH and SONET frame structures.

The ComSoc Guide to Next Generation Optical Transport: SDH/SONET/OTN,
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1.1 HISTORY

Based on the experience with *Plesiochronous Digital Hierarchy* (PDH) equipment and networks, the telecommunication carriers and equipment vendors identified issues that should be resolved by developing a new methodology to transport digital signals. This resulted in a set of requirements:

- Standardize the optical interface specifications for the *Network Node Interface* (NNI) to enable the use of equipment from different vendors at both ends of a connecting optical fiber, i.e., the "*mid-span meet*" requirement.

  In PDH the signals at the distribution racks are specified but the line interfaces are proprietary requiring the installation of single vendor equipment at both ends.
- Use "*true*" synchronous multiplexing to simplify the access to any of the multiplexed signals in the network hierarchy. Synchronous multiplexing also simplifies the synchronization of the whole transport network to a single clock.

  In the PDH hierarchy it is required to demultiplex at every level to access the required signal. Each multiplex level has its own slightly different clock. Plesio-chronous = almost − synchronous
- Specify sufficient overhead capabilities to fully support automation of the operations, administration, and maintenance of the equipment and the transported signal.

  PDH has a very limited overhead capacity.
- Specify a multiplexing scheme that can be extended easily to accommodate higher bit-rates. It is expected to provide the transport infrastructure for worldwide telecommunications for at least the next two or three decades (starting in 1990).

  In PDH adding a higher multiplex is complex.
- The base rate of the new methodology should facilitate the transport of the highest PDH rate existing at that time.

The timeline for the development of the requirements mentioned above is:

1984 MCI raises the "mid-span meet" issue to various standards bodies: Exchange Carriers Standards Association (ECSA), Bell Communications Research (Bellcore, now Telcordia), American National Standards Institute (ANSI), and International Telecommunication Union (ITU-T, former CCITT).

1985 Bellcore proposes the concept for a *Synchronous Optical NETwork* (SONET). ANSI drives the standardization efforts (initially 400 proposals). The base rate is related to the DS-3 signal bit-rate of 45 Mbit/s. Frame structures are specified to transport DS-1, DS-2, and DS3.

1986 ITU-T initiates the development of *Synchronous Digital Hierarchy* (SDH) standards. The base rate is related to the E4 signal bit-rate of 140 Mbit/s. Frame structures are specified to transport E1, E2, E3, and E4. This is supported by the *European Telecommunications Standards Institute* (ETSI).

1987 An attempt to align SDH and SONET fails, the SONET base rate does not match any of the European PDH rates nor will it be able to transport E4 efficiently. There is also a significant difference in the frame format: SDH has 9 rows and 270 columns, while SONET has 13 rows and 180 columns.

1988 ANSI adjusts the SONET specification to meet the SDH requirements of the rest of the world. Agreement is reached on defining the base rate of SDH as 155 Mbit/s. The SONET STS-3 frame structure is the equivalent of the SDH STM-1.

1990 Multivendor SDH and SONET networks are operational.

See also the IEEE Communications Magazine, March 1989, "*SONET: Now It's the Standard Optical Network*."

Since 1990 the SDH and SONET specifications have been extended based on demand for the transport of new tributary signals and also based on new capabilities provided by the evolution in component technology. The latter enabled the transport of multiple colors (wavelengths) on a single optical fiber. This was one of the reasons to start development of a new set of recommendations to use this feature: the *Optical Transport Network* (OTN), sometimes called "*digital wrapper*." OTN has the capability to wrap any service into a digital optical container and thus enables network transparency that provides the flexibility to support all traffic types: voice, video, and data. The OTN technology seamlessly combines multiple networks and services into a common, future-ready infrastructure. Because it was designed to be transparent to the service type, all services carried over the OTN are given individual treatment, preserving any native functionality and performance without compromising the integrity of the underlying services.

2000 Specification of *Virtual conCATenation* (VCAT) to provide more flexibility in matching the bandwidth of the client signal. This is initiated by a high demand for transporting emerging technologies with non (SDH) standard bit-rates.

2001 Specification of the *Link Capacity Adjustment Scheme* (LCAS) to provide the ability to change the size of a VCAT signal. Specification of the *Generic Framing Procedure* (GFP) used for mapping packet-based signals into the constant bit-rate SDH signals. These two methodologies enable the use of SDH and SONET as transport capability in *Next Generation Networks* (NGN).

2001 The first version of the OTN recommendations is published.

2004 The specification of the Ethernet transport network is initiated by the ITU-T.

2005 The specification of a Transport Profile of MPLS (MPLS-TP) is started by the ITU-T and will be further developed in close cooperation with the IETF.

1.2 CONVENTIONS

In this book I have tried to cover both the SDH standards as specified, or recommended, by the global standardisation committee, the ITU-T, as well as the regional European standardization committee ETSI and the SONET standards specified by the regional standardization committee ANSI and the generic requirements specified by Telcordia. When appropriate I will mention differences between the SDH and SONET standards.

To avoid confusion that would be caused by mixing terminology and abbreviations used in the SDH, SONET, and OTN standards I will use a limited set of abbreviations and terms. However, when necessary, the equivalent SONET term is added in brackets {*term*}. To avoid even more confusion I will use abbreviations and terms that are already in use by the ITU-T.

1.2.1 SDH and SONET Terms

In this book I will use the term ***Section*** for the means for transportation of information between two network elements and make no distinction between an SDH Regenerator Section, in SONET termed {***Section***} and an SDH Multiplex Section, in SONET termed {***Line***}, i.e., the physical connection including the regenerators. Both SDH and SONET use the term ***Path*** for the connection through a network between the points where a container is assembled and dis-assembled. The total information transported over a path, i.e., the payload plus the OA&M information is in SDH normally referred to as a ***Trail***.

- An SDH ***Container*** is the equivalent of a SONET ***Synchronous Payload***. It is the general term used to refer to the payload area in a frame structure.
- An SDH ***Virtual Container*** **(VC)** is the equivalent of a SONET ***Synchronous Payload Envelope*** that exists in two forms, the **{STS-n SPE}** and the **{VTn SPE}**. It is used to refer to a **Container** and its associated **OverHead (OH)** information fields.
- **C–n**—a continuous payload ***Container*** of order n (n = 4, 3, 2, 12, 11). Generally used for all multiplex levels present in the STN. Sometimes used only to indicate the higher order levels of multiplexing (n = 4, 3).

- **C–m**—a continuous payload ***Container*** of order m (m = 2, 12, 11). Commonly used for the lower order levels of multiplexing.
- **C–n–X**—a contiguous concatenated payload ***Container*** of size X times the size of a container C–n. For (n = 4, 3) the X = 1…256 and for (n = 2, 12, 11) the X = 1…64.
- **VC–n**—a ***Virtual Container*** of order n (n = 4, 3, 2, 12, 11), that transports a container C–n together with its associated VC Path OverHead (VC POH). A VC–4 can also be sub-structured to transport three TUG–3s and similarly a VC–3 can transport seven TUG–2s. The SONET equivalents for the higher order multiplexes are for the VC–4: the ***Synchronous Transport Signal*** {STS–3c SPE}, and for the VC-3: the {STS–1 SPE}.
- **VC–m**—a ***Virtual Container*** of order m (m = 2, 12, 11), that transports a container C–m together with its associated VC POH. Commonly used for the lower order levels of multiplexing. The SONET equivalents for the lower order multiplexes are for the VC-2: the ***Virtual Tributary*** {VT6 SPE}, for the VC–12: the {VT2 SPE}, and for the VC–11: the {VT1.5 SPE}.
- **VC–n–Xc**—a ***Contiguous concatenated VC-n*** of order n (n = 4, 3, 2), that transports a container C–n–X together with its associated VC POH. The SONET equivalents are for the VC–4–Xc: the {STS–3–Xc} and for the VC–3–Xc: the {STS–1–Xc}.
- **VC–n–Xv**—a ***Virtual concatenated VC-n*** of order n (n = 4, 3, 2, 12, 11), that transports a container C–n–X by using X individual VC–n and their associated VC POH. The SONET equivalents are the {STS–3c–Xv SPE}, the {STS–1–Xv SPE} and the {VTn–Xv SPE}.
- **TU–n**—a ***Tributary Unit*** of order n (n = 2, 12, 11), that transports a VC–n together with its associated VC pointer.
- **TUG–n**—a ***TU Group*** of order n (n = 3, 2), that provides the flexibility for mapping tributaries. A TUG–3 can accommodate a single TU–3 or seven TUG–2s. A TUG–2 can accommodate a single TU–2, three TU–12s, or four TU–11s. The SONET equivalent is a {VT Group}.
- **AU–n**—an ***Administrative Unit*** of order n (n = 3, 4, 4-Nc and N = 4, 16, 64, 256), that transports a VC–n together with its associated VC pointer.
- **AUG–N**—an ***AU Group*** of multiplex level N (N = 1, 4, 16, 64, 256), that provides the multiplexing capability. For N = 4, …, 256 it either accommodates a single AU–4–Nc or four AUG–N′, where N′ = N/4. An AUG–1 can accommodate a single AU–4 or three AU–3.
- **STM-N**—a ***Synchronous Transport Module*** of multiplex level N (N = 1, 4, 16, 64, 256), that transports an AUG-N together with the Multiplex Section overhead (MS OH) and the Regenerator Section overhead (RS OH). Equivalent SONET structures are the {STS-M where M = 3, 12, 48, 192, 768}.

1.2.2 OTN Terms

- **OPUk**—an ***Optical channel Payload Unit*** of order k (k = 1, 2, 3), the equivalent of an SDH C–n. It has its own payload-associated overhead.
- **OPUk–Xv**—a ***Virtual concatenated OPUk***. Each of the X OPUk in an OPUk–Xv is transported as an individual OPUk in the OTN.
- **ODUk**—an ***Optical channel Data Unit*** of order k (k = 1, 2, 3), the equivalent of an SDH VC–n, that transports an OPUk. It has its own path-associated overhead.
- **ODUk–Xv**—a ***Virtual concatenated ODUk***. Used to transport an OPUk–Xv.
- **OTUk**—an ***Optical channel Transport Unit*** of order k (k = 1, 2, 3), the equivalent of an SDH TUG–n. It has its own transport-associated overhead.
- **OTM–n,m**—an ***Optical Transport Module***, n represents the maximum number of supported wavelengths and m represents the (set of) supported bit-rate. Similar to the SDH STM-N it has its associated Optical Multiplex Section (**OMS**) overhead and Optical Transmission Section (**OTS**) overhead.

1.2.3 Drawing Conventions

The order of transmission of information in all the figures in this book is first from left to right, and then from top to bottom. In frame structures the information in the first row is transmitted first, followed by the information in the second row, etc. Within each byte or octet the most significant bit is transmitted first. The Most Significant Bit (MSB) (bit 1) is shown at the left side in all the figures and the Least Significant Bit (LSB) at the right side.

1.3 STANDARD DOCUMENTS FROM DIFFERENT SDOS

Table 1-1 lists all the known standards and recommendation specifically related to SDH, SONET, and OTN developed by the international standardization organization and two regional standards organizations. A subdivision is made to group the specifications of different subjects used in the implementation of equipment and deployment in the transport network.

TABLE 1-1. List of standards

	ITU-T Recommendation[1]	ETSI Standards[1]	ATIS/ANSI Standards[2]
Source:	www.itu.int	www.etsi.org	www.atis.org
Physical interfaces	G.703 G.957 G.959.1 (OTN) G.691 G.692	EN 300 166 EN 300 232	T1.102 T1.105.06 T1.416 T1.416.01 T1.416.02 T1.416.03 *(GR 1374)*
UNI/NNI interfaces	G.8012 (ETH) G.8112 (MPLS-TP)	—	—
Network architecture	G.803 G.805 G.809 G.8010 (ETH) G.8110 (MPLS-TP)	ETR 114	T1.105.04
Structures & mappings	G.704 G.707 G.709 (OTN) G.7041 (GFP) G.7042 (LCAS) G.7043 (PDH-VCAT) G.8040 (GFP/PDH)	EN 300 167 EN 300 147 ETS 300 337	T1.105 T1.105.02 *(GR 253)*
Equipment functional characteristics (models)	G.783 G.798 (OTN) G.8021 (ETH) G.8121 (MPLS-TP) G.781 (sync) G.806 (generic)	EN 300 417-1-1 EN 300 417-2-1 EN 300 417-3-1 EN 300 417-4-1 EN 300 417-5-1 EN 300 417-6-1 EN 300 417-7-1 EN 300 417-9-1 EN 300 417-10-1 ETS 300 635 ETS 300 785	*(GR 496)* *(GR 499)* *(GR 2979)* *(GR 2996)*
Laser safety	G.664	—	—
Transmission protection	G.841 G.842 G.8031 (ETH linear) G.8032 (ETH ring) G.8131 (MPLS-TP lin.) G.8132 (MPLS-TP ring) G.808.1 (generic)	ETS 300 746 EN 300 417-1-1 EN 300 417-3-1 EN 300 417-4-1 TS 101 009 TS 101 010	T1.105.01 *(GR 1230)* *(GR 1400)*

TABLE 1-1. *Continued*

	ITU-T Recommendation[1]	ETSI Standards[1]	ATIS/ANSI Standards[2]
Restoration	M.2102		—
Information model	G.774 G.774.01 G.774.02 G.774.03 G.774.04 G.774.05 G.774.06 G.774.07 G.774.08 G.774.09 G.774.10 M.3100 (generic)	ETS 300 304 ETS 300 484 ETS 300 413 ETS 300 411 ETS 300 493 EN 301 155	T1.119 T1.119.01 T1.119.02 T1.245 *(GR 836)* *(GR 1042)* *(GR 2950)*
Equipment management	G.784 G.8051 (ETH) G.8151 (MPLS-TP)	EN 301 167 EN 300 417-7-1	*(GR 3000)*
Network management	G.831 G.850–G.859	ETS 300 810	T1.204 *(GR 3001)*
Management communications interfaces	G.773		T1.105.04 *(GR 376)*
Error performance [equipment level]	G.783 G.784 O.150 O.181 O.182 (OTN)	EN 300 417-1-1 EN 300 417-2-1 EN 300 417-3-1 EN 300 417-4-1 EN 300 417-5-1 EN 300 417-6-1 EN 300 417-7-1 EN 300 417-9-1 EN 300 417-10-1	—
Error performance [network level]	G.826 G.827 G.828 G.829 G.8201 (OTN) M.2101 M.2101.1 M.2102 M.2110 M.2120 M.2130 M.2140	EN 301 167	T1.105.05 T1.231 T1.514 *(GR 2991)*

TABLE 1-1. *Continued*

	ITU-T Recommendation[1]	ETSI Standards[1]	ATIS/ANSI Standards[2]
Jitter & wander performance	G.813 G.822 G.823 G.824 G.825 G.8251 (OTN) G.783 O.172 O.173 (OTN)	EN 300 462-5-1 EN 302 084	T1.105.03 T1.105.03a T1.105.03b
Synchronization [clocks & network architecture]	G.803 G.810 G.811 G.812 G.813 G.8261 (PTN) G.8252 (ETH)	EN 300 462-1 EN 300 462-2 EN 300 462-3 EN 300 462-4 EN 300 462-5 EN 300 462-6 EN 300 417-6-1 EG 201 793	T1.101 T1.105.09

Note 1: The ITU-T recommendations and ETSI standards can be downloaded freely from www.itu-t.int and www.etsi.org, respectively.
Note 2: The ANSI standards can be ordered at www.atis.org. This column also lists Telcordia documents (*in italics*), which can be ordered at www.telcordia.com.