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## Introduction

### *To the next generation SDH/SONET*

*Although it is assumed that the reader has a basic understanding of the operation of the Synchronous Digital Hierarchy (SDH) and/or the Synchronous Optical Network (SONET), this book starts with a short history of the revolutions and evolutions that have taken place during and after the design of the SDH/SONET standards.*

*The conventions adopted in this book will be explained to avoid confusion caused by the different terminology used in the SDH, SONET, OTN and PDH standards and to provide a consistent description of the features of the next generation SDH/SONET.*

### 1.1 HISTORY

During the evolution of digital multiplexes, e.g. from the primary rate multiplexes 2048 kbit/s E1 and 1544 kbit/s DS1 up to the fourth order multiplexes 139.264 Mbit/s E4 and 274.176 Mbit/s DS4, in general referred to as Pleisiochronous Digital Hierarchy (PDH) signals, it became clear that the application of these multiplexes in larger networks required an improvement of the network synchronisation and a better Operations, Administration and Maintenance (OA&M) structure. The OA&M structure should provide a measure for the quality of the transported signals and a validation of the connection through the network. The existing PDH structure could not be used to fulfil these

requirements and so a revolution was needed; it was a revolution because it requires new equipment and a new network structure. The revolutionary Synchronous Digital Hierarchy (SDH) and Synchronous Optical Network (SONET) were designed to meet the required improvements. A PDH network has a strong vertical structure and is star shaped. The SDH/SONET network has a strong horizontal structure with ring shaped hierarchical layers and Add/Drop Multiplexors (ADM) providing the interconnection between the layers and connections for client or tributary signals. The first generation SDH/SONET appeared after the standardisation in 1986.

As the PDH multiplexes were designed to transport voice signals and private lines the SDH and SONET multiplex were designed initially to transport the same signals. Because of their nature of multiplexing they are referred to as Time Division Multiplexes (TDM). An additional advantage of the revolutionary design of SDH/SONET is the multiplexing structure where tributary signals are mapped as payload into containers. These containers, together with their own timing information and OA&M overhead, are transported as independent virtual containers in the SDH/SONET network. The multiplex structure of SDH/SONET is also designed to enable the evolution to higher order multiplexes to meet the demand for transporting more and more payload. See Chapter 2 for the evolution of SDH/SONET to provide the increased bandwidth by defining Contiguous conCATenation (CCAT) and the introduction of CCAT in existing networks by using Virtual conCATenation (VCAT). Once defined, it appeared that VCAT could also be used to provide efficiently a matching bandwidth for non-voice related signals. The most recent defined application is the deployment of VCAT to enable the gradual introduction of an all-Optical Transport Network (OTN) as an evolution of existing SDH/SONET networks. The multiplexing of the optical signal or wavelength is commonly referred to as Wavelength Division Multiplexing (WDM).

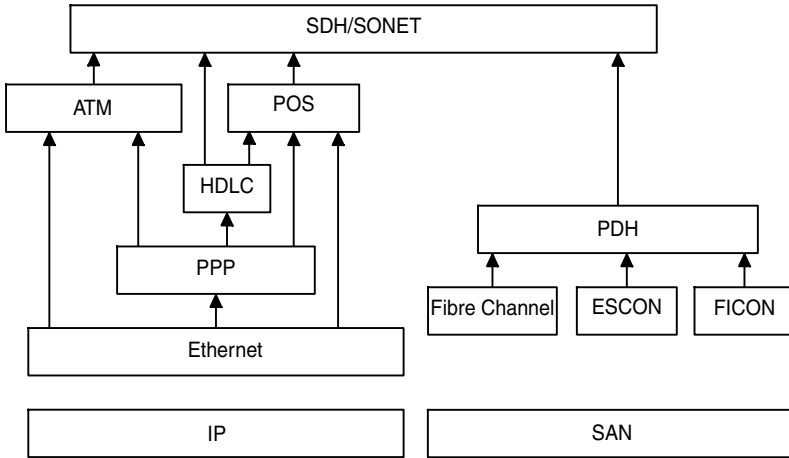
In the last years of the 20th century, due to the enormous popularity of the Internet and the expansion of Internet Protocol (IP) based networks, an explosion in the number of IP-based end systems occurred, e.g. Internet Service Providers (ISP) Points of Presence (PoP). At the same time, the application of Ethernet was growing beyond the limits of the Local Area Network (LAN) into the Metro Area Network (MAN) and the even larger Wide Area Networks (WAN). Also the demand for data storage shared among systems in remote locations was growing, i.e. the introduction of a Storage Area

Network (SAN). The expansion of these packet data and streaming data based signals created a growing demand for transport of data in an efficient and secure way. Because of the existence and availability of SDH/SONET networks, including the provided Quality of Service (QoS) and connection protection mechanisms, it was clear that SDH/SONET could provide the transport of data signals in the same way as it had already been doing for voice signals and private lines. Initially, however, the transport bandwidth provided by SDH/SONET containers did not match efficiently the bandwidth required by the data signals. In Chapter 2, it is explained how VCAT can provide an efficient transport of data signals.

As the demand by data applications for bandwidth can vary in time, the payload container capacity provided by VCAT is not always utilized efficiently. To improve this utilisation, a protocol has been designed to flexibly adjust the payload container size: the Link Capacity Adjustment Scheme (LCAS). Chapter 3 provides the methodology used by the LCAS protocol, i.e. the LCAS overhead signals added to the virtual concatenation control information that were required to provide a flexible and hitless increase or decrease of a virtual concatenated signal. Chapter 3 also provides a description of the operation of LCAS during an increase and decrease of the payload bandwidth. The LCAS protocol is described in state machine diagrams in Chapter 4. The state machines are depicted using the ITU-T Specification and Description Language (SDL). Chapter 5 contains examples of the operation of LCAS under different conditions by using Time Sequence Diagrams (TSD).

The major part of IP, Ethernet traffic is transported over the public network by encapsulating it in Frame Relay, Point-to-Point Protocol (PPP), High-Level Data Link Control (HDLC), Packet over SONET/SDH (POS) or Asynchronous Transport Multiplex (ATM). SAN protocols such as Fibre Channel (FC), Enterprise Systems CONnectivity (ESCON) and Fibre CONnectivity (FICON) have originally been transported over the public network by using proprietary (and in most cases vendor-specific) solutions. Figure 1.1 gives an example of how packet data can be transported.

Currently, most line interfaces for IP edge routers and most Frame Relay and PPP interfaces operate at PDH rates or low order SDH/SONET rates, although STM-16/OC-48 and STM-64/OC-192 interfaces are being introduced very rapidly, especially in MAN and WAN networks. Considering the widespread availability of inexpensive 10/100/1000 Mbit/s Ethernet interfaces on Customer Premises



**Figure 1.1** Packet data transfer

Equipment (CPE), e.g. switches and routers, the growing need to improve the transport capabilities of ISP PoP equipment and SAN interconnectivity, as well as the recent introduction of Virtual LAN based Virtual Private Networking (VPN), there is a renewed interest for a QoS friendly, standard-based mechanism to transport IP, Ethernet and SAN traffic over TDM and WDM networks. Based on this interest, a mapping of all these Variable Bit Rate (VBR) signals into a Constant Bit Rate (CBR) signal was developed. This mapping is defined as Generic Frame Procedure (GFP) and is described in detail in Chapter 6.

## 1.2 CONVENTIONS

This book tries to cover both the SDH standards as defined or recommended by the global standardisation committee ITU-T and by the regional European standardisation committee ETSI and the SONET standards as defined by regional standardisation committee ANSI T1. When appropriate, mention will also be made of connections to equivalent uses of VCAT in OTN, also defined by the ITU-T.

To avoid confusion that would be caused by mixing terminology and abbreviations used in the SDH, SONET, OTN and PDH standards,

this book uses a limited set of abbreviations and terms. To avoid even more confusion, it employs abbreviations and terms that are already in use by the ITU-T.

- An SDH *Container* is the equivalent of a SONET *Synchronous Payload Envelope (SPE)*.
- $C-n$  ( $n = 3,4$ ) – a continuous payload container of type  $n$ , a term used by the ITU-T. Normally represented as a frame structure by using a matrix with 9 rows by  $p$  columns where each cell contains an octet. The frame time is  $125 \mu\text{s}$ . This container can transport a CBR signal of  $9 * p * 8 * 8 \text{ kbit/s}$ . A container  $C-4$  ( $p = 260$ ) can transport  $149\,760 \text{ kbit/s}$  and a container  $C-3$  ( $p = 84$ ) can transport  $48\,384 \text{ kbit/s}$ .
- $C-m$  ( $m = 2,12,11$ ) – a continuous payload container of type  $m$ . Represented as a frame structure by using a matrix with 4 rows by  $q$  columns where each cell contains an octet. The frame time is  $500 \mu\text{s}$ . This container can transport a CBR signal of  $4 * q * 8 * 8 \text{ kbit/s}$ . A container  $C-2$  ( $q = 106$ ) will transport  $6784 \text{ kbit/s}$ , a container  $C-12$  ( $q = 43$ )  $2176 \text{ kbit/s}$  and a container  $C-11$  ( $q = 25$ )  $1600 \text{ kbit/s}$ .
- $VC-n$  – a Virtual Container of type  $n$ , equal to a container  $C-n$  with an additional 9 bytes Path Overhead and optional fixed stuff. In this book, it is used for the SDH virtual containers  $VC-4$  and  $VC-3$ , and the equivalent SONET Synchronous Transport Signal  $STS-3c$  SPE and  $STS-1$  SPE.
- $VC-m$  – a Virtual Container of type  $m$ , equal to a container  $C-m$  with an additional 4 bytes Path Overhead and optional fixed stuff. In this book, it is used for the SDH virtual containers  $VC-2$ ,  $VC-12$  and  $VC-11$ , and the SONET virtual tributaries  $VT6$  SPE,  $VT3$  SPE,  $VT2$  SPE and  $VT1.5$  SPE.
- $C-n-Xc$  – a contiguous concatenated payload container of size  $X$  times the size of a container  $C-n$ .
- $VC-n-Xc$  – a Virtual Container transporting a container  $C-n-Xc$  with an additional Path overhead and optional fixed stuff columns.
- $VC-n-Xv$  –  $X$  virtual concatenated  $VC-n$ , used in this book to indicate any of the following: a  $VC-4-Xv$ , a  $VC-3-Xv$ , an  $STS-3c-Xv$  SPE and an  $STS-1-Xv$  SPE.
- $VC-m-Xv$  –  $X$  virtual concatenated  $VC-m$ , used in this book to indicate any of the following: a  $VC-2-Xv$ , a  $VC-12-Xv$ , a  $VC-11-Xv$ , a  $VT6-Xv$  SPE, a  $VT3-Xv$  SPE, a  $VT2-Xv$  SPE and a  $VT1.5-Xv$  SPE.

- $S_n$  – used in functional models to refer to the higher order VC- $n$  layer ( $n = 3, 4, 4\text{-Xc}$ ) or lower order VC-3 layer.
- $S_m$  – used in functional models to refer to the lower order VC- $m$  layer ( $m = 11, 12, 2$ ).
- $OPU_k$  ( $k = 1, 2$ ) – (OTN) an Optical channel Payload Unit of type  $k$  can be compared to an SDH payload container C- $n$ .
- $OPU_k\text{-Xv}$  –  $X$  virtual concatenated  $OPU_k$ . Each  $OPU_k$  in an  $OPU_k\text{-Xv}$  is transported in an individual ODUk.
- $ODU_k$  – (OTN) an Optical channel Data Unit of type  $k$ . An ODUk can be compared to an SDH virtual container VC- $n$ .
- $ODU_k\text{-Xv}$  –  $X$  virtual concatenated ODUk.
- $E1$  – a 2048 kbit/s framed PDH signal connected to electrical interface E12. It has a basic frame structure of 32 timeslots or octets at a frame rate of 125  $\mu$ sec. Two octets (consecutive timeslots 0) are used for the transport overhead. For additional Quality of Service, a CRC-4 multi-frame is used consisting of 16 basic frames at a multi-frame rate of 2 ms.
- $E3$  – a 34 368 kbit/s framed PDH signal connected to electrical interface E31. It has a frame structure of 59 octet columns and 9 rows plus 6 octets at a frame rate of 125  $\mu$ sec. 7 octets are used for the transport overhead.
- $DS1$  – a 1544 kbit/s framed PDH signal connected to electrical interface E11. It has a basic frame structure of 24 timeslots or octets and a single bit transport overhead per frame at a frame rate of 125  $\mu$ sec. 24 basic frames form an extended superframe with a frame rate of 3 ms.
- $DS3$  – a 44 736 kbit/s framed PDH signal connected to electrical interface E32. It has a basic frame structure of 680 bit columns and 7 rows. Each row consists of 8 blocks containing 1 transport overhead bit and 84 payload bits. The frame rate is 106  $\mu$ sec.

In this book, the term *Section* is used for the means for transportation of information between two network elements and no distinction is made 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 disassembled. 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*.

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. 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.

