SDH/SONET Explained in Functional Models

Modeling the Optical Transport Network

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To my wife Leontine for her support and patience,
and in memory of my parents

Contents

Preface

The use of a natural language to describe the functionality in transmission networks and transport equipment will lead to misinterpretation of the written requirements and cause equipment not to interoperate. The growth in complexity of the functionality and diversity of the optical transport network capabilities to be described, and the number of different users, for example, system engineers, marketing, customers, developers, standards representatives, meant that it was necessary to develop and define a common language.

In this book I describe this language, i.e. the methodology that is used to model the functionality of transport networks and transport equipment. The functional modeling methodology is applicable in connection-oriented networks, e.g. PDH, SDH, SONET, OTN, as well as connectionless networks, e.g. Ethernet, MPLS. The emphasis in this book is on the explanation of the functional modeling methodology and its use as a description tool. Examples are provided to help the reader in understanding modeling technique.

Based on my experience with the use of functional models over the past ten years, I expect that many readers of this book will be System Engineers and Functional Architects who are employed by Optical Transport Network operators, Optical Transport equipment manufacturers and device manufacturers, especially those who are responsible for transport-related functionality at Networking or Network Element level. It will help them to use and develop functional models in the area of their responsibility.

I assume that optical network, equipment and device development engineers as well as system verification, system test and interoperability test engineers will use this book as a guideline.

Finally, I hope that this book will be used by students in telecommunications technology and by members of the IEEE community as a reference to acquire the skill of functional modeling.

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Huub van Helvoort, M.S.E.E., Senior member IEEE.

Abbreviations

AcSQ	Accepted Sequence number
ADM	Add-Drop Multiplexer
AI	Adapted Information
AIS	Alarm Indication Signal (i.e. Alarm Inhibit Signal)
ANSI	American National Standards Institute
AP	Access Point
API	Access Point Identifier
APS	Automatic Protection Switch
ATM	Asynchronous Transport Module
AU	Administrative Unit
BP	Bridge Protocol
CBRx	Constant BitRate signal with approximate bitrate x
CCAT	Contiguous conCATenation
CCITT	Comite Consulatif Telegraphique et Telephonique (now ITU-T)
CI	Characteristic Information
CP	Connection Point
CRC	Cyclic Redundancy Check
DCC	Data Communications Channel
DCN	Data Communications Network
DXC	Digital Cross-Connect
EOW	Engineer Order Wire
ETSI	European Telecommunications Standards Institute
FCS	Frame Check Sequence
FD	Flow Domain
FDFr	Flow Domain Fragment
FEBE	Far End Block Error
FERF	Far End Receive Failure
FOP	Failure of Protocol

FP	Flow Point
FPP	Flow Point Pool
GFP	Generic Framing Process
IEEE	Institute of Electrical and Electronics Engineers
IP	Internet Protocol
ISO	International Organization for Standardization
ITU-T	International Telecommunications Union—Telecommunication Standardization Sector (former CCITT)
LAN	Local Area Network
LC	Link Connection
LCAS	Link Capacity Adjustment Scheme
LOA	Loss of Alignment
LOM	Loss of Multi-frame
MAC	Media Access Control
MAN	Metro Area Network
MI	Management Information
MND	Member Not De-skewable
MP	Management Point
MPLS	Multi-Protocol Label Switching
MS-SPRing	Multiplex Section—Shared Protection Ring
MSn	Multiplex Section of level n
MSAP	Multi-Service Access Platform
MSPP	Multi-Service Provisioning Platform
MSSP	Multi-Service Switching Platform
MSTP	Multi-Service Transport Platform
MSU	Member Service Unavailable
MTBF	Mean Time Between Failures
MTTR	Mean Time To Repair
NC	Network Connection
NNI	Network to Network Interface
NUT	Non-pre-emptible Unprotected Traffic
OAM/OA&M	Operation Administration and Maintenance
OSI	Open Systems Interconnection
OOS	OTM Overhead Signal
OSn	Optical Section of level n
OTM	Optical Transport Module
OTN	Optical Transport Network
PCI	Protocol Control Information
PDH	Plesiochronous Digital Hierarchy
PLC	Partial Loss of payload Capacity
POH	Path OverHead

PRC	Primary Reference Clock
QoS	Quality of Service
RDI	Remote Defect Indication
REI	Remote Error Indication
RI	Remote Information
RP	Remote Point
RSn	Regenerator Section of level n
Sk	Sink
So	Source
SAN	Storage Area Network
SD	Signal Degrade
SDH	Synchronous Digital Hierarchy
SDU	Service Data Unit
SF	Signal Fail
SLA	Service Level Agreement
SNC	Sub-Network Connection
SNCP	Sub-Network Connection Protection
SNC/I	SNCP using Inherent monitoring
SNC/N	SNCP using Non-intrusive monitoring
SNC/S	SNCP using Sub-layering
SONET	Synchronous Optical Network
SQ	Sequence number
SQM	SQ Mismatch
SSD	Server Signal Degraded
SSF	Server Signal Failed
SSM	Synchronization Status Messaging
STM-N	Synchronous Transport Module (level) N
TCM	Tandem Connection Monitoring
TCP	Termination Connection Point
TFP	Termination Flow Point
TI	Timing Information
TLC	Total Loss of payload Capacity
TP	Timing Point
TSD	Trail Signal Degraded
TSF	Trail Signal Fail
TTI	Trail Trace Identifier
TU	Tributary Unit
UNI	User to Network Interface
VC–n	Virtual container (level) n
VCAT	Virtual conCATenation
VCG	Virtual Concatenation Group
WAN	Wide Area Network

1

Introduction

A telecommunications network is a complex network that can be described in a number of different ways depending on the particular purpose of the description. In this book the optical transport network will be described as a network from the viewpoint of the capability to transfer information. More specifically, the functional and structural architecture of optical transport networks is described independently of the networking technology, for example, distribution, platforms, packaging. The methodology used for this description is commonly referred to as functional modeling and is used in many standards documents to describe the functional architecture of existing and evolving PDH, SDH, OTN, ATM, Ethernet and MPLS networks. The functional model is also used extensively by operators to describe their network and by manufacturers to describe their equipment or devices.

1.1 HISTORY

The development of functional models for use in telecommunication networks was a combined effort of network operators and equipment manufacturers. After an extensive analysis of existing transport network structures, the functional modeling methodology was first introduced in the standards documents of the *European Telecommunications Standards Institute* (ETSI) around 1995. In the ETSI standards the methodology was used to model the SDH network and its equipment. After the introduction and standardization in ETSI, the *International Telecommunications Union – Telecommunication Standardization Sector*

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(ITU-T) also adapted the functional modeling in 1997. Although initially used for the specification of SDH, later it was applied in the specification of other technologies. Currently, work is in progress on modeling Ethernet networks. There is an increased interest in the *American National Standards Institute* (ANSI) to adopt the functional model methodology in their standards.

1.2 JUSTIFICATION

There were several reasons to start the study and development of a methodology to model a transport network or equipment in a functional way. Some of these reasons were:

- *Increased complexity.* Owing to the natural growth of optical transport networks and equipment, the contained functionality increased as well.
- *Increased variety.* Owing to the growth in complexity, the number of required functions also increased as well as the number of possible combinations of these functions.
- *Multiple applications.* The same transport equipment is labeled differently, e.g. multiplexer, cross-connect, line system, depending on the application in the network topology.
- *Written requirements.* Generally, in a natural language, there have the following disadvantages:
  - no common language; requires translation
  - voluminous; easy to lose overview
  - inconsistent; often dependent on the writer's background
  - ambiguous; uses a natural language
  - incomplete.

These reasons meant that it became more and more difficult to manage the transport network and equipment. It was almost impossible to guarantee the compatibility and interoperability of equipment based solely on written documentation. Consequently, this created the need for a new language that showed similarities where networks and equipment were similar and differences where they were dissimilar.

Considering the reasons mentioned above, the following requirements were taken as input for the study to establish a new description methodology, i.e. a common language:

- It should provide a flexible description of the functional architecture at transport network level that takes into account varying partitioning and layering requirements.
- It should identify functional similarities and differences in heterogeneous technology-based layered transport network architecture.
- It should be able to produce network element functional models that are traceable to and reflective of network level requirements.
- It should establish a rigorous and consistent relationship between transport network functional architecture and management information models.

In addition, the established methodology should have the following characteristics:

- it is simple;
- it is short;
- it is visual;
- it contains basic elements;
- it provides combination rules;
- it supports generic usage;
- it has recursive structures;
- it is implementation independent;
- it is transport level independent;
- it has the capability to automate generation and verification.

The result of the study is the definition and standardization of the functional modeling methodology. With a functional model it is possible to present:

- Optical Transport Network capabilities, independent of actual deployed equipments.
- Transport Equipment capabilities, independent of actual equipment implementation.

The unambiguous specification produced by applying the methodology will provide a unique definition of transport networks and equipment towards:

- Optical Transport Network operators;
- Optical Transport Equipment and Device manufacturers;
- Network Management Systems and Element Management Systems.

1.3 REMARKS ON THE CONCEPT

The analysis and decomposition of existing transmission networks resulted in the definition of the atomic functions that are used in the functional modeling methodology. These atomic functions can be used to compose the functional models of the same existing, legacy and future transmission networks.

This concept is not new. Some other technologies that have used atomic models are listed below.

- Hardware (analog). The atomic functions used in this technology are, for exampl, resistors, capacitors, inductors, diodes, and transistors. These atomic functions can be used to model an analog circuit or network, for example, an amplifier, a cable or even a digital circuit like an OR gate as illustrated in Figure 1.1.
- Hardware (digital). The atomic functions utilized in this technology are, for example, AND, NAND, OR, NOR, INVERT and XOR gates. Even though these functions can be represented by the atomic functions of the analog hardware as shown in the previous example, in this technology they would provide too much detail and would make the description of the digital circuit too complex. Thus the gates are in fact compound functions representing the analog

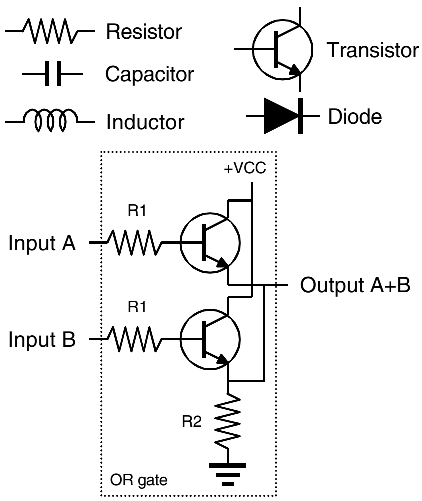

Figure 1.1 electric circuit symbols and example.

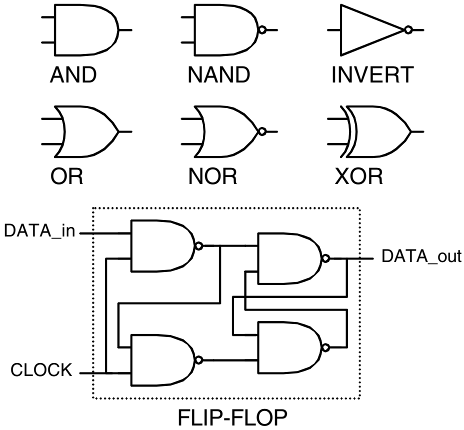

Figure 1.2 logic symbols and example.

hardware atomics. These atomic functions in this technology can again be used to model a digital circuit, for example, a flip-flop, which can be used as a compound function in other models, a microprocessor or a digital transmission function (e.g. a multiplexer, framer). Figure 1.2 shows the atomics and an example circuit.

- Software (assembly language). Even the primitives in textual form can be considered as building blocks to describe a particular function. Examples of the textual atomic functions are JUMP, JMPNC, LOAD, STORE, SUB, XOR and NOP instructions. These atomic functions can be used to model a process. Figure 1.3 depicts a simple example. Instructions can be grouped together to form procedures that can be CALLed and RETURNed from when finished; these procedures can be used as compound functions.

  Assembly language is however very implementation specific; every vendor has its proprietary set of atomic models and there are no generic assembly language atomic functions.
- Software (higher order language). The ITU-T has defined a higher order language to provide a vendor independent programming capability for telecommunication processes: CHILL, the CCITT Higher Level Language (for a description, see ITU-T Rec. Z.200, 1999). Another and more widespread higher order language is the C programming language (Kernighan and Ritchie, 1978). The atomic functions are, for example, FOR, WHILE, IF-THEN-ELSE,

```
;-------------------------------------------------------
; Read the input port, IPORT, 5 times, and store into
; 5 consecutive memory locations, elements of array
; DATA[i]. Also read each element of DATA[i] and
; write it to output port, OPORT.
;--------------------------------------------------------
.EQU    IPORT     0              ; #define IPORT

.EQU    OPORT     1              ; #define OPORT

;

        XOR       R0, R0, R0     ; clear register R0

LBL0:   SUBL      NULL, R0, 5    ; as long as R0 < 5 {

        JMPNC     LBL1           ;

        LOADP     R1, IPORT      ; read input port into R1

        DSTOREM   DATA(R0), R1   ; store R1 in memory

        DLOADM    R2, DATA(R0)   ; read memory into R2

        STOREP    OPORT, R2      ; write R2 to output port

        ADDL      R0, R0, 1      ; increment R0

        JMP       LBL0           ; }


LBL1:   NOP                      ; end of program.
```

Figure 1.3 Assembly language example.

CASE, and ASSIGNMENT. Frequently used routines can be collected in a library and used as compound functions. These atomic functions can be used to model a process, for example, the same as the assembly language example above (see Figures 1.3 and 1.4.)

Higher order languages are independent of the implementation. There are, however, only a few (micro-) processors that can interpret this higher order language; a translator, or compiler, is used to generate the implementation specific assembly language understood by a particular (micro-) processor.

- Process descriptions using state diagrams. The atomic functions in this methodology (e.g. SDL Specification and Description Language, ITU-T Rec. Z.100, 2002) are STATE, INPUT, OUTPUT, TASK and DECISION. The TASK symbol may represent a procedure that

```
;----------------------------------------------------
; Read the input port 5 times, and store into
; 5 consecutive memory locations, elements of array
; DATA[i]. Also read each element of DATA[i] and
; write it to output.
;----------------------------------------------------
main()
{
        int c;
        int DATA[5];

        c = 0;

        while ( c < 5) {
        c = getchar();
        DATA[I] = c;
        putchar() = c;
        }
}
       /*end of program. */
```

Figure 1.4 C Language example.

can again be specified in SDL and can be considered as a compound function. These atomic functions can be used to describe a process, for example, subscriber signaling, Link Capacity Adjustment Scheme (LCAS, see ITU-T Rec. G.7042, 2004). Hardware and software designers can use these models when implementing a specific process. Figure 1.5 shows an example of the graphical representation: SDL/GR. This is a part of the SDL diagram describing the Source side processing in LCAS (see ITU-T Rec. G.7042, 2004).

SDL also has a textual phrase representation as shown in Figure 1.6: SDL/PR. Tools exist that use this text to generate the graphical representation and and/or generate executable code for testing purposes.

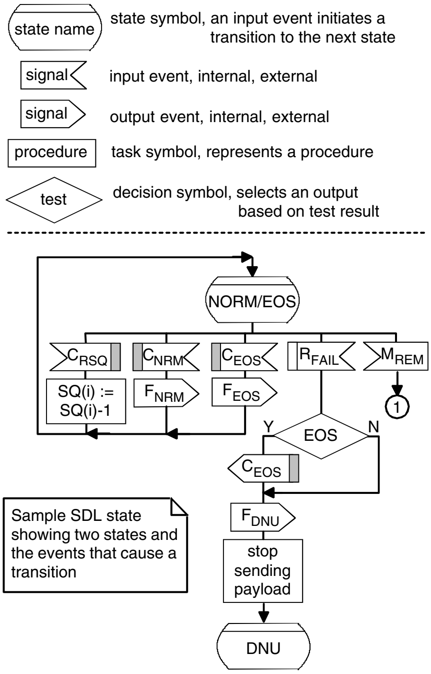

Figure 1.5 SDL/GR functional model example.

```
PROCESS LCAS_source_side;

        STATE NORM/EOS;
                INPUT CRSQ;
                        TASK 'SQ(i) := SQ(i) - 1';
                        NEXTSTATE NORM/EOS;
                INPUT CNRM;
                        OUTPUT FNRM;
                        NEXTSTATE NORM/EOS;
                INPUT CEOS;
                        OUTPUT FEOS;
                        NEXTSTATE NORM/EOS;
                INPUT RFAIL;
                        DECISION 'MBRST';
                        (EOS): OUTPUT CEOS;
                        (NORM): ;
                        ENDDECISION;
                        OUTPUT FDNU;
                        TASK'stop_sending_payload';
                        NEXTSTATE DNU;
                INPUT MREM;
                        .... ;
        STATE DNU;
                .... ;
ENDPROCESS;
```

Figure 1.6 SDL/TR example.

1.4 STANDARDS STRUCTURE

The modeling conventions are described in ETSI EN 300 417-1-1(2001) and the equipment specifications in the remainder of this series (EN 300 417-2-1 to EN 300 417-7-1, EN 300 417-9-1 and EN 300 417-10-1). The methodology is also described by Brown (1996).

After the functional modeling was accepted by ETSI it was also introduced in the recommendations of the ITU-T. The ANSI has not yet adopted the functional modeling methodology to describe SONET networks and equipment (see ANSI T1.105, 2001). Currently there is a whole suite of Recommendations covering the full functionality of network equipment:

- The principles of functional modeling are defined in ITU-T Rec. G.805 (2000) for the transport of connection oriented signals and, since the introduction of packet oriented data transport, ITU-T Rec. G.809 (2003) defines the connectionless principles.
- Functional modeling conventions and generic equipment functions are defined in ITU-T Rec. G.806 (2004).
- The SDH network architecture can be found in ITU-T Rec. G.803 (2000) and the equipment specification in ITU-T Rec. G.783 (2004).
- The OTN network architecture can be found in ITU-T Rec. G.872 (2001) and the equipment specification in ITU-T Rec. G.798 (2004).
- For PDH only the equipment specification is available in ITU-T Rec. G.705 (2000).
- The ATM network architecture is defined in ITU-T Rec. I.326 (1995) and the functional characteristics are described in ITU-T Rec. I.732 (2000).
- The Ethernet network architecture can be found in ITU-T Rec. G. 8010 (2004) and the equipment specification in ITU-T Rec. G. 8021 (2004).
- The MPLS network architecture can be found in ITU-T Rec. G. 8110 (2005) and the equipment specification in draft ITU-T Rec. G. mplseq (2005).
- Network and Network Element management functionality is described in ITU-T Rec. G.7710 (2001) for common equipment, in G.784 (1999) for SDH networks and in G.874 (2001) for OTN equipment. MPLS OAM functionality is defined in ITU-T Rec. Y 1710 (2002).