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Technical Specification

**Transmission and Multiplexing (TM);
Optical Access Networks (OANs) for evolving services;
ATM Passive Optical Networks (PONs)
and the transport of ATM over digital subscriber lines**

Reference

DTS/TM-03024 (bs000icr.PDF)

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Foreword

This Technical Specification (TS) has been produced by ETSI Technical Committee Transmission and Multiplexing (TM).

1 Scope

The present document is applicable to Optical Access Networks (OANs) that support evolving services, i.e. services which could exceed 2 Mbit/s bearer capability. Access networks which also support existing services such as telephony and narrowband ISDN are also considered. Evolutionary scenarios for existing ANs are identified, considering Hybrid optical Fibre-Twisted Pair (HFTP) and Hybrid optical Fibre-Coaxial (HFC) networks. ANs which do not contain one or more Optical Distribution Networks (ODNs) are out of scope of the present document.

The present document includes a detailed specification for an ATM Passive Optical Network (PON) based on a TDMA multiple access technique. This system is applicable to multiple network architectures such as Fibre To The Cabinet (FTTCab) and Fibre To The Home (FTTH). ATM PONs which use FDMA as a multiple access technique are not precluded, but are not specified in detail in the present document.

For OANs involving metallic (twisted pair) sections, the present document provides guidelines on the requirements for digital subscriber line systems, where these form part of an OAN.

Functional architectures are provided which identify examples of the evolution of ODNs and HFC networks according to service demand.

2 References

The following documents contain provisions which, through reference in this text, constitute provisions of the present document.

- References are either specific (identified by date of publication, edition number, version number, etc.) or non-specific.
- For a specific reference, subsequent revisions do not apply.
- For a non-specific reference, subsequent revisions do apply.
- A non-specific reference to an ETS shall also be taken to refer to later versions published as an EN with the same number.

[1] ITU-T Recommendation G.902: "Framework recommendation on functional access networks".

[2] ITU-T Recommendation I.413: "ISDN User-Network Interfaces - B-ISDN user-network interface".

[3] ITU-T Recommendation I.414: "ISDN User-Network Interfaces - Overview of recommendations on layer 1 for ISDN and B-ISDN customer access".

[4] DAVIC 1.0 Part 04: "Delivery System Architecture and Interfaces".

[5] ATM Forum BTD-RBB-001.04: "Baseline text for the Residential Broadband Working Group".

[6] ETS 300 324-1: "Signalling Protocols and Switching (SPS); V interfaces at the digital Local Exchange (LE); V5.1 interface for the support of Access Network (AN); Part 1: V5.1 interface specification".

[7] ETS 300 347-1: "Signalling Protocols and Switching (SPS); V interfaces at the digital Local Exchange (LE); V5.2 interface for the support of Access Network (AN); Part 1: V5.2 interface specification".

[8] EN 301 005-1: "V interfaces at the digital Service Node (SN); Interfaces at the VB5.1 reference point for the support of broadband or combined narrowband and broadband Access Networks; Part 1: Interface specification".

[9] EN 301 217-1 (1998): "V interfaces at the digital Service Node (SN); Interfaces at VB5.2 reference point for the support of broadband or combined narrowband and broadband access networks; Part 1: Interface specification".

[10] ETS 300 001: "Attechement to the Public Switched Telephone Network (PSTN); General technical requirements for equipment connected to an analogue subscriber interface in the PSTN".

[11] ETS 300 448: "Business TeleCommunications (BTC); Ordinary quality voice bandwidth 2-wire analogue leased line (A2O); Connection characteristics and network interface presentation".ref_300448 * Mergeformat

[12] ETS 300 449: "Business TeleCommunications (BTC); Special quality voice bandwidth 2-wire analogue leased line (A2S); Connection characteristics and network interface presentation".

[13] ETS 300 451: "Business TeleCommunications (BTC); Ordinary quality voice bandwidth 4-wire analogue leased line (A4O); Connection characteristics and network interface presentation".

[14] ETS 300 452: "Business TeleCommunications (BTC); Special quality voice bandwidth 4-wire analogue leased line (A4S); Connection characteristics and network interface presentation".

[15] ETS 300 012-1: "Integrated Services Digital Network (ISDN); Basic rate user-network interface; Part 1: Layer 1 specification".

[16] ETS 300 011-1: "Integrated Services Digital Network (ISDN); Primary rate User-Network Interface (UNI); Part 1: Layer 1 specification".

[17] ETS 300 233: "Integrated Services Digital Network (ISDN); Access digital section for ISDN primary rate".

[18] ITU-T Recommendation G.703: "Physical/electrical characteristics of hierarchical digital interfaces".

[19] ITU-T Recommendation G.704: "Synchronous frame structures used at 1 544, 6 312, 2 048, 8 488 and 44 736 kbit/s hierarchical levels".

[20] ETS 300 742: "Transmission and Multiplexing (TM); Physical layer User Network Interface (UNI) for 2 048 kbit/s Asynchronous Transfer Mode (ATM) signals".

[21] I-ETS 300 811: "Broadband Integrated Services Digital Network (B-ISDN); Transmission Convergence (TC) and Physical Media Dependent (PMD) sublayers for the SB reference point at a bit-rate of 25,6 Mbit/s over twisted pair cable".

[22] ETS 300 299: "Broadband Integrated Services Digital Network (B-ISDN); Cell based user network access for 155 520 kbit/s and 622 080 kbit/s; Physical layer interfaces for B-ISDN applications".

[23] ETS 300 300: "Broadband Integrated Services Digital Network (B-ISDN); Synchronous Digital Hierarchy (SDH) based user network access; Physical layer User Network Interfaces (UNI) for 155 520 kbit/s and 622 080 kbit/s Asynchronous Transfer Mode (ATM) B-ISDN applications".

[24] ETS 300 288: "Business TeleCommunications (BTC); 64 kbit/s digital unrestricted leased line with octet integrity (D64U); Network interface presentation".

[25] ETS 300 418: "Business Telecommunications (BTC); 2 048 kbit/s digital unstructured and structured leased lines (D2048U and D2048S); Network interface presentation".

[26] ETS 300 419: "Business TeleCommunications (BTC); 2 048 kbit/s digital structured leased lines (D2048S); Connection characteristics".

[27] ETS 300 247: "Business Telecommunications (BT); Open Network Provision (ONP) technical requirements; 2 048 kbit/s digital unstructured leased line (D2048U) Connection characteristics".

[28] ETS 300 686: "Business TeleCommunications (BTC); 34 Mbit/s and 140 Mbit/s digital leased lines (D34U, D34S, D140U, D140S); Network interface presentation".

[29] ETS 300 376-1: "Signalling Protocols and Switching (SPS); Q3 interface at the Access Network (AN) for configuration management of V5 interfaces and associated user ports; Part 1: Q3 interface specification".

[30] ETS 300 378-1: "Signalling Protocols and Switching (SPS); Q3 interface at the Access Network (AN) for fault and performance management of V5 interfaces and associated user ports; Part 1: Q3 interface specification".

[31] EN 301 271: "Telecommunications Management Network (TMN); Management interfaces associated with the VB5.1 reference point".

[32] TS 101 270-1: "Transmission and Multiplexing (TM); Access transmission systems on metallic access cables; Very high speed Digital Subscriber Line (VDSL); Part 1: Functional requirements".

[33] ETR 328: "Transmission and Multiplexing (TM); Asymmetric Digital Subscriber Line (ADSL); Requirements and performance".

[34] EN 301 163-1-1: "Transmission and Multiplexing (TM); Generic requirements of Asynchronous Transfer Mode (ATM) transport functionality within equipment; Part 1-1: Functional characteristics and equipment performance".

[35] ITU-T Recommendation I.432.1: "B-ISDN user-network interface physical layer specification - general characteristics".

[36] ANSI T1.413 Issue 2: "Network and Customer Installation Interfaces - Asymmetric Digital Subscriber Line (ADSL) Metallic Interface".

[37] ITU-T Recommendation I.432.2: "B-ISDN UNI Physical layer specification for 155 520 kbit/s and 622 080 kbit/s".

[38] ITU-T Recommendation G.982: "Optical access networks to support services up to the ISDN primary rate or equivalent bit rates".

[39] ITU-T Recommendation I.732: "Functional characteristics of ATM equipment".

[40] ITU-T Recommendation G.671: "Transmission characteristics of passive optical components".

[41] ITU-T Recommendation G.652: "Characteristics of a single-mode optical fibre cable".

[42] ITU-T Recommendation I.326: "Functional architecture of transport networks based on ATM".

[43] ITU-T Recommendation I.321: "B-ISDN protocol reference model and its application".

[44] ITU-T Recommendation G.958: "Digital line systems based on the synchronous digital hierarchy for use on optical fibre cables".

[45] ITU-T Recommendation G.957: "Optical interfaces for equipments and systems relating to the synchronous digital hierarchy".

[46] ITU-T Recommendation G.783: "Characteristics of synchronous digital hierarchy (SDH) equipment functional blocks".

[47] ITU-T Recommendation I.361: "B-ISDN ATM layer specification".

[48] ITU-T Recommendation I.610: "B-ISDN operation and maintenance principles and functions".

[49] ITU-T Recommendation M.3010: "Principles for a Telecommunications management network".

[50] ITU-T Recommendation I.356: "B-ISDN ATM layer cell transfer performance".

[51] IEC 60721-3-1: "Classification of environmental conditions - Part 3: Classification of groups of environmental parameters and their severities Section 1: Storage".

[52] IEC 60801-2: "Electromagnetic Compatibility for Industrial-Process Measurement and Control Equipment, Part 2: Electrostatic Discharge".

[53] IEC 60801-3: "Electromagnetic Compatibility for Industrial-Process Measurement and Control Equipment, Part 3: Radiated Electromagnetic Field requirements".

[54] IEC 60825-1: "Safety of LASER Products - Part 1: Equipment classification, requirements and user's guide".

[55] EN 300 429: "Digital Video Broadcasting (DVB); Framing structure, channel coding and modulation for cable systems".

[56] DAVIC 1.0 Part 08: "Lower layer protocols and physical interfaces".

[57] ISO/IEC DIS 13818-6: "Information technology - Generic coding of moving pictures and associated audio information - Part 6: Extensions for DSM-CC (ISO/IEC/JTC1/SC29/WG11)".

[58] IEEE 802.14-Draft 2 Revision 2: "Cable-TV Access Method and Physical Layer Specification".

3 Abbreviations

For the purposes of the present document, the following abbreviations apply:

AAL	ATM Adaptation Layer
ADSL	Asymmetric Digital Subscriber Line
AF	Adaptation Function
AN	Access Network
ANI	Access Node Interface
APS	Automatic Protection Switching
ATM	Asynchronous Transfer Mode
ATU	ADSL Transceiver Unit
BA	Basic Access
BER	Bit Error Ratio
B-ISDN	Broadband ISDN
BIP	Bit Interleaved Parity
CATV	Community Antenna Television (Cable TV)
CCIR	International Radio Consultative Committee
CID	Consecutive Identical Digit
COF	Co-Ordination Function
CPE	Cell Phase Error
CPN	Customer Premises Network
CRC	Cyclic Redundancy Check
DAVIC	Digital Audio Visual Council
DCC	Data Communiation Channel
DC/Dem	Downconverter/demodulator
DMux	Demultiplexer
DSL	Digital Subscriber Line
DSM-CC	Digital Storage Medium Connection Control
DTMF	Dual Tone Multi-Frequency
DVB	Digital Video Broadcast
EDC	Error Detection Code
E/O	Electrical/Optical
EOC	Embedded Operations Channel
FDM	Frequency Division Multiplex
FDMA	Frequency Division Multiple Access
FTTB	Fibre To The Building
FTTCab	Fibre To The Cabinet

FTTC	Fibre To The Curb
FTTH	Fibre To The Home
FTTO	Fibre To The Office
HEC	Header Error Control
HFC	Hybrid Fibre Coax
HFTP	Hybrid Fibre Twisted Pair
IEC	International Electrotechnical Commission
i/f	interface
IoD	Information on Demand
ISDN	Integrated Services Digital Network
ISO	International Standards Organization
IW	Interworking
LAN	Local Area Network
LCD	Loss of Cell Delineation
LCF	Laser Control Field
LM	Layer Management
LOA	Loss of Acknowledge
LSB	Least Signfiant Bit
LT	Line Terminal
MAC	Medium Access Control
MIS	Link Mismatching
MLM	Multi-Longitudinal Mode
MMF	Multi-Mode Fibre
Mod/UC	Modulator/upconverter
MSB	Most Significant Bit
MUX	Multiplexer
NIU	Network Interface Unit
NO	Netwok Operator
NRZ	Non Return to Zero
NT	Network Termination
NTR	Network Timing Reference
OAM	Operations, Administration and Maintenance
OAN	Optical Access Network
ODF	Optical Distribution Frame
ODN	Optical Distribution Network
O/E	Optical/Electrical
OLT	Optical Line Termination
ONP	Open Network Provision
ONU	Optical Network Unit
OpS	Operations System
ORL	Optical Return Loss
PCS	Plastic Clad Silica
PDS	Passive Double Star
PHY	Physical Layer
PLOAM	Physical Layer OAM
PMD	Physical Medium Dependent
PMS-TC	Physical Medium Specific Transmission Convergence
PON	Passive Optical Network
PRA	Primary Rate Access
PRBS	Pseudo-Random Binary Sequence
PST	PON Section Trace
PSTN	Public Switched Telephone Network
QoS	Quality of Service
QPSK	Quaternary Phase Shift Keying
RAU	Request Access UNit
RF	Radio Frequency
RLCD	Remote Loss of Cell Delineation
RMS	Root-Mean-Square
RXCF	Receiver Control Field
SCM	Subcarrier Multiplexing

SDH	Synchronous Digital Hierarchy
SLM	Single-Longitudial Mode
SMF	Singlemode fibre
SN	Serial Number
SN	Service Node
SNI	Service Node Interface
SNR	Signal to Noise Ratio
SOHO	Small Office/Home Office
STB	Set-top box
TA	Terminal Adapter
TC	Transmission Convergence
TDM	Time Division Multiplex
TDMA	Time Division Multiple Access
TE	Terminal Equipment
TP	Transmission Path
TPA	Transmission Protocol Adaptation
TPS-TC	Transport Protocol Specific Transmission Convergence
TS	Transport Stream
TTP	Trail Termination Point
UI	Unit Interval
UNI	User Network Interface
UTP	Unshielded Twisted Pair
VC	Virtual Channel
VCI	Virtual Channel Identifier
VDSL	Very high speed Digital Subscriber Line
VP	Virtual Path
VPI	Virtual Path Identifier
WDM	Wavelength Division Multiplexer
xDSL	general DSL technology/system

4 Overview of optical access networks

4.1 General considerations

For the purposes of the present document, an AN may be defined as the system providing signal transport and associated functions between one or more SNIs and a multiplicity of UNIs. A single AN is assumed to be provided and managed by a single network operator. An OAN is an AN which contains one or more distribution networks which employ optical fibre, although other transmission media may additionally be employed within the AN.
See ITU-T Recommendation G.902 [1] for a medium-independent framework describing general access networks.

The ANs considered include those supporting both digital and analogue services. Examples of digital access types which may be provided by an AN is listed in ITU-T Recommendation G.902 [1], Appendix I, tables II.1 to II.4.

ANs which support both narrowband and broadband services are considered. In practice, a requirement of access networks is that they flexibly support demand for higher information bandwidths and increasingly diverse services in a way which makes effective use of existing network resources. It is a common requirement that this evolution take place in a service-independent manner, i.e. functional elements which are specific to certain services are external to the AN.

A wide variety of evolving services can be envisaged for residential, business and SOHO (small office/home office) use, for example:

- information-on-demand;
- education;
- service-on-demand (e.g. home shopping);
- teleworking;
- file transfer;
- internet access;
- LAN interconnection.

4.2 Interfaces to the AN

When the AN is viewed as a single functional element, it is bounded by UNIs on the customer side, one or more SNIs on the network side, and typically an interface to a network management system. For ANs which can be modelled according the ISDN reference configuration, these boundaries are represented by the V, T and Q reference points respectively, as shown in figure 1.

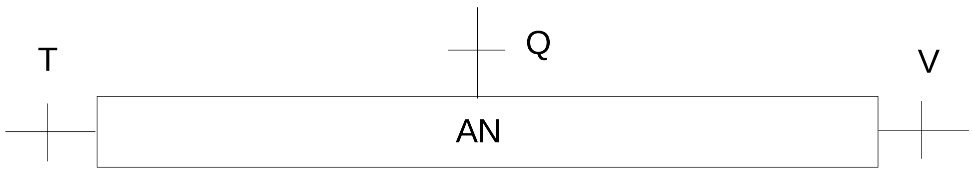
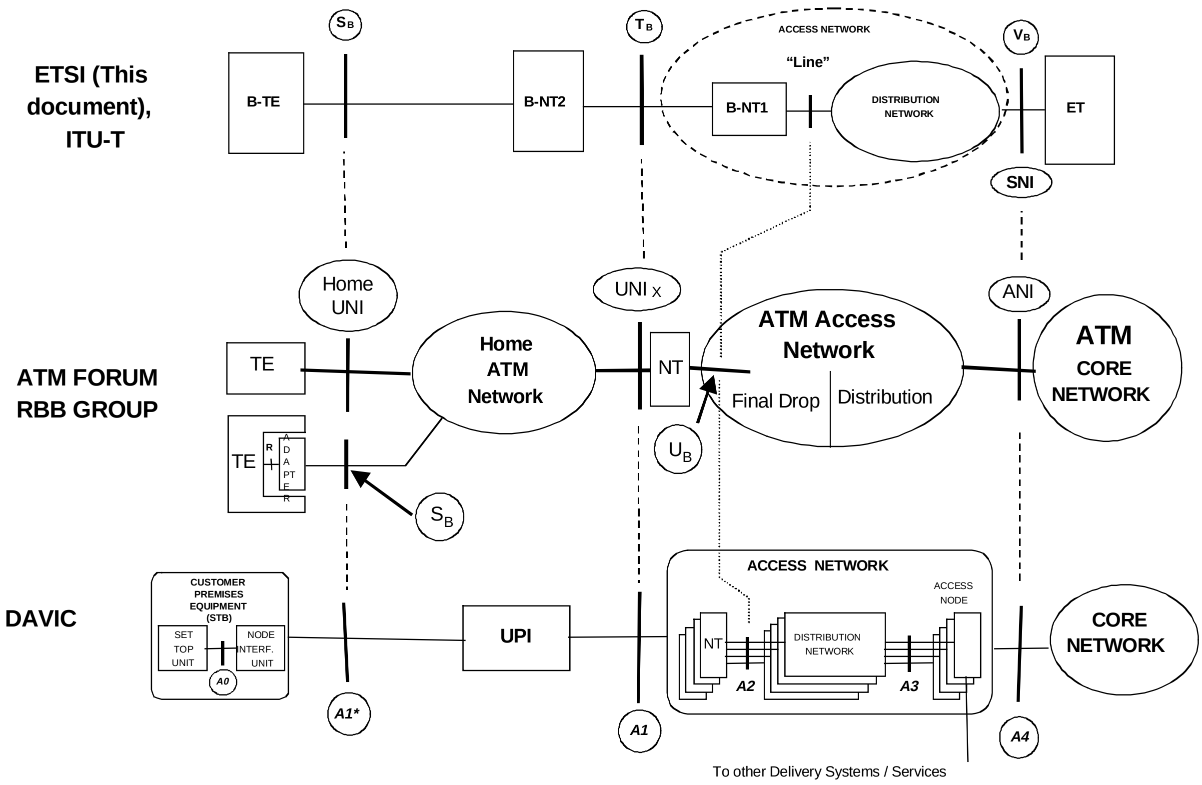


Figure 1: Boundaries of AN according to ISDN reference model

Other types of AN may use different conventions to describe its reference points and interfaces. A comparison with two common alternatives is shown in figure 2.



NOTE: For examples, see ITU-T Recommendations I.413 [2] and I.414 [3]; DAVIC specification 1.0 (Part 04) [4], and ATM Forum Document BTD-RBB-001.04 [5].

Figure 2: Alternative AN models

4.2.1 SNIs

The following are examples of SNIs, for the case of digital service nodes:

V5.1	ETS 300 324-1 [6]
V5.2	ETS 300 347-1 [7]
VB5.1	EN 300 005-1 [8]
VB5.2	EN 301 217-1 [9]

An AN may support one or more SNIs, which may be provide connections to SNs operated by the same or different network operators as the AN. The VB5.1 standard listed above describes a possible mechanism to support narrowband services (as supported by V5 interfaces) over a broadband SNI.

4.2.2 UNIs

The following are examples of UNIs which may be supported by an AN:

Analogue telephony services	NET4: ETS 300 001 [10]
Analogue leased line services	ETS 300 448 (ONP A2O) [11], ETS 300 449 (A2S) [12], ETS 300 451 (A4O) [13], ETS 300 452 (A4S) [14]
ISDN-BA	ETS 300 012 [15]
ISDN-PRA	ETS 300 011 [16], ETS 300 233 [17]
Circuit switched and packet data services	The customer interface for data services should be 64 kbit/s according to G.703 [18], 2 Mbit/s according to G.703 and G.704 [19], or according to B-ISDN. The conversion to the appropriate data network interface may be provided by an adaptation unit which is not part of the AN.
B-ISDN	ETS 300 742 [20]; physical layer UNI for 2 Mbit/s ATM signals
B-ISDN	I-ETS 300 811 [21]; physical layer at S_B reference point for 25,6 Mbit/s signals (further study is required on the use of this physical interface at the T_B reference point).
B-ISDN	ETS 300 299 [22] for cell-based UNI
B-ISDN	ETS 300 300 [23] for SDH-based UNI

Digital leased line services:

64 kbit/s G.703	ETS 300 288 (ONP D64U) [24]
1 984 kbit/s	ETS 300 418 [25], ETS 300 419 (ONP D2048S) [26]
2 048 kbit/s	ETS 300 418 [25], ETS 300 247 (ONP D2048U) [27]
n × 64 kbit/s (n ≤ 30)	ETS 300 418 [25], ETS 300 419 (ONP D2048S) [26]
34 Mbit/s	ETS 300 686 (ONP D34U, D34S) [28]

4.2.3 AN management interfaces

The following management interfaces are appropriate for ANs that support V5 and VB5 SNIs:

Q3 for V5	ETS 300 376-1 [29]
	ETS 300 378-1 [30]
Q3 for VB5	Under study in TC/TMN.
	NOTE: Work item DEN/TMN-00003 (see Bibliography).
	EN 301 271 [31]

4.3 Elements of ANs

Figure 1 showed the AN as a single functional entity. However, a consideration of practical networks requires this functional block to be decomposed into smaller units. Figure 3 shows the decomposition of this simple representation into an AN comprising an optical distribution segment based on singlemode fibre and a drop segment which may be based on one of a variety of physical media.

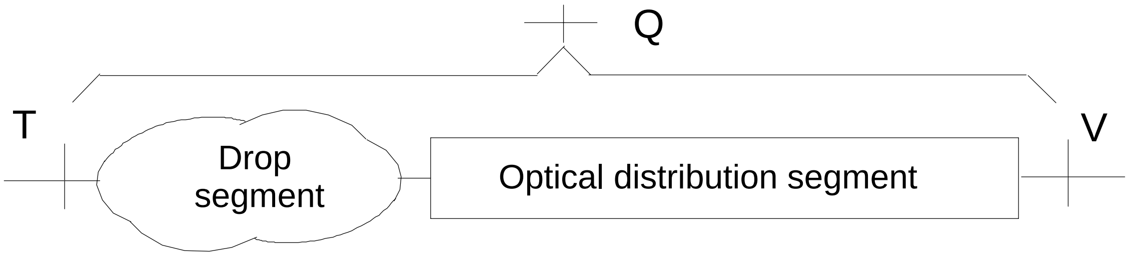


Figure 3: Segmentation of AN

Figure 4 takes this analysis a stage further and identifies physical units within the drop segment and optical distribution segment.

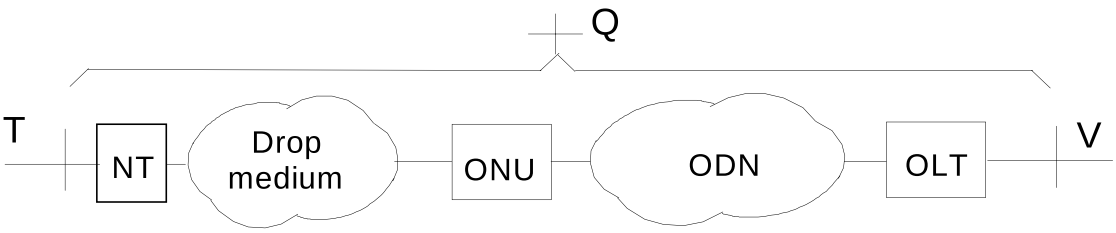


Figure 4: Further decomposition of AN

Figure 4 includes as examples the terms OLT and ONU to represent physical units which bound the ODN. In some network other terms are typically used. The case where the singlemode optical fibre part of the AN extends as far as the NT function is a special case of the above. In this instance, no explicit consideration of a drop segment is appropriate.

Clause 6 and annex A provide a detailed specification for an ODN and for core function of the functions of the OLT and ONU, in the case of an ATM PON based on TDM/TDMA techniques. Annexes B to E provide supporting information for this ATM PON specification.

5 Evolution of existing networks

The most favourable options for the upgrade of existing networks to support evolving services may depend to a large extent on the nature and extent of any transmission infrastructure already in place. This is particularly true for the drop section of the access network, where the replacement costs per customer of the existing transmission medium are typically highest. The present document considers in differing degrees hybrid OANs which employ either of two types of drop media:

- twisted metallic pairs, i.e. a HFTP network;
- coaxial cable i.e. a HFC network.

Other drop media (e.g. radio) may also be employed, resulting in other varieties of hybrid AN.

Future OANs are expected to meet the following requirements:

a) They will exploit more fully the technical capability of fibre to give node consolidation - numerous small switch sites for narrow band services could be eliminated and additional broadband services could be offered from a small number of service nodes.

b) They will exploit more fully the technical capability of the existing copper/coax drop network to enable broadband service delivery.

Two basic strategies are possible: 1) a changeout strategy where the new fibre network delivers service to both broadband and ongoing narrowband customers, 2) an overlay strategy where the network is built to deliver service only to those customers taking the new broadband services. Each of these options has different relative cost advantages but the choice between these two options may well differ and will depend on a complex array of factors including the pace at which new service revenues are expected to develop, the penetration expected for broadband services, the regulatory climate and the age/state of the existing AN.

Annex F contains a functional architecture of an ODN, and describes the alternatives for its evolution.

Annex G describes the evolution options for HFC networks, including reference configurations of example networks, their functional architectures, and open issues to be considered in future standardization activities.

Annex H provides examples of approaches to the overlay and integration of an HFTP system on existing networks.

With the exception of the annexes, the remainder of this specification deals with HFTP systems.

6 ATM PON specifications

This clause specifies requirements of an ATM PON system capable of supporting a full range of services. While non-ATM solutions and other AN architectures such as HFC are not precluded, their detailed specifications are out of scope of the present document.

The multiplexing technique for downstream (OLT to ONU) transmission, and the access technique for upstream (ONU to OLT) transmission shall be according to one of two options, namely either TDM/TDMA as specified in subclause 6.1, or FDM/FDMA (frequency division multiplexing/frequency division multiple access) as described in subclause 6.2.

6.1 TDM/TDMA solution

TDM/TDMA is the preferred option for ATM PON systems in the medium-term to allow multi-vendor interoperability and cost savings for silicon.

The ATM PON architecture and requirements shall be according to annex A.

With reference to the ATM PON described in annex A, annex B describes examples of the causes of optical reflections within the ODN, annex C describes the overall reflectance model for the ODN, annex D provides examples of ranging flow diagrams and annex E considers AN protection and survivability issues.

6.2 FDM/FDMA solution

FDM/FDMA is an option for near-term implementations. A detailed specification of FDM/FDMA systems is out of scope of the present document.

7 ATM transport over xDSL

7.1 Scope

This clause addresses implementation aspects specific to the transport of ATM over Access Networks using Digital Subscriber Line (xDSL) technology for part or all of the network.

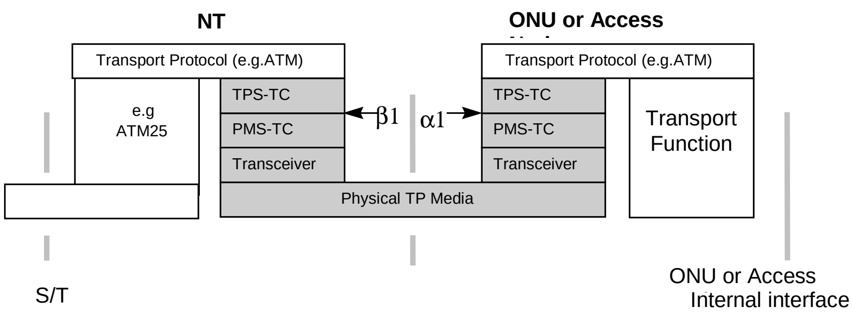
The scope for this clause is to provide a specification for the transport of ATM over xDSL systems that is consistent with the work of ETSI TM6, namely TS 101 270-1 for VDSL [32] and ETR 328 for ADSL [33]. This clause aims to provide comprehensive guidelines for the selection of bearer channels for the transport of ATM and to provide clear interpretations of the pertinent sections of the above technical reports. It provides an outline description of the relevant Transmission Convergence (TC) sublayer, as well as a description of the xDSL specific TC and PMD layer primitives toward the ATM layer and management entities of the network elements (e.g. Access Node, ONU, NT) which incorporate such functions.

With reference to figure 5, it is the intention of this clause to describe the functional blocks of the xDSL based access network from the Transport Function at the ATM Core network side (in the case of ADSL) or from the Transport Function at the ONU side (in the case of VDSL) to the T (or other) interface, and not to specify the physical level of the interfaces. The physical level interfaces are described in ETR 328 for ADSL [33] and TS 101 270-1 for VDSL [32], to which the reader is referred for further details.

In order to clarify the functional description, the TC layer has been subdivided in TPS-TC sublayer and Physical PMS-TC sublayer.

7.2 Specific Reference model

Figure 5 shows xDSL applications reference model respectively and the functional elements.



TPS-TC Transport Protocol Specific Transmission Convergence Layer
PMS-TC PMD Specific Transmission Convergence Layer

NOTE: TPS-TC sublayer is service specific.

Figure 5: xDSL system applications reference model

7.2.1 Functional decomposition

7.2.1.1 The α and β interfaces

The hypothetical α and β interfaces are defined to enable a common transceiver description for application to various transport protocols (e.g. ATM and SDH) This interface partitions the transmission convergence layer into Physical Media Specific TC (PMS-TC) and Transport Protocol Specific TC (TPS-TC) parts.

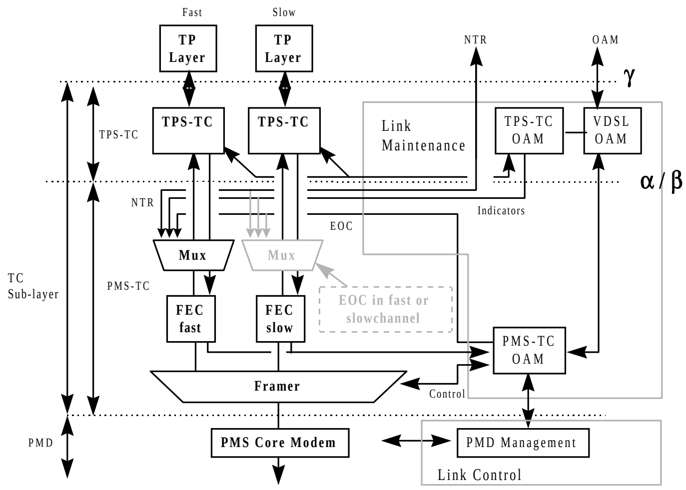


Figure 6: Generic xDSL functional block diagram

Figure 6 shows the generic functional block diagram which indicates the disposition of major functions partitioned by the α and β interfaces.

These interfaces define the separation between the application dependent Transport Protocol Specific (TPS) part and the application independent Physical Media Specific (PMS) core modem parts of the xDSL transmission system.

The TPS part includes transport protocol layer functions outside the scope of this specification, and Transport Protocol Specific Transmission Convergence layer functions (TPS-TC).

The application independent part contains Physical Media Specific Transmission Convergence layer functions (PMS-TC), and modem (PMD) functions.

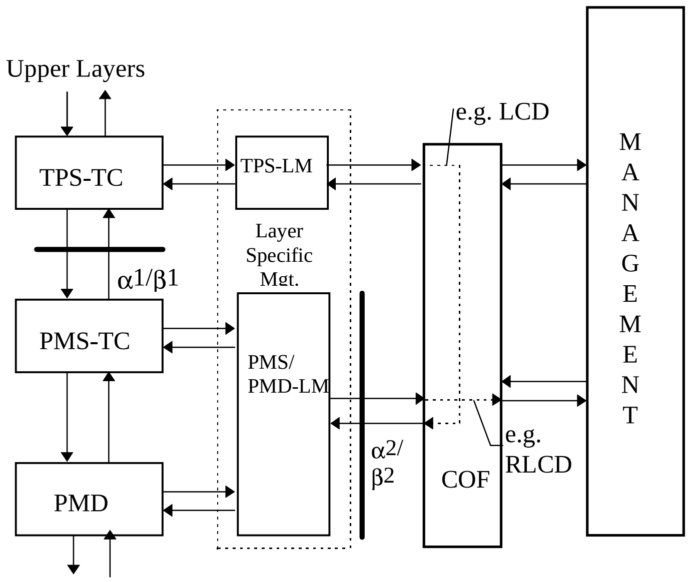


Figure 7: Generic xDSL functional reference model

Furthermore, as shown in figure 7, in the xDSL equipment functional reference model, two α interfaces are defined for the LT:

α1: Interface between TPS-TC and PMS-TC Transport functions.

α2: Interfaces between PMD-TC & PMD-LM PMS-TC & PMS-LM.

The TPS-TC, TPS-LM and the interface between the TPS-LM and Management Layer are according to EN 301 163-1-1 [34].

For the NT, β1, β2 apply respectively.

A Coordination Function, as part of the Layer Management (LM), is required for either in the case that the management information (primitives) needs to be conveyed transparently to the Management Layer, or in case that the management information requires fast response between two separate layers (e.g. LCD from the TPS-TC sink direction to the PMS-TC source direction where appropriate RDI should be generated).

By convention the PMS-TC, TPS-TC, and modem layers are assumed to include applicable OAM functions. The overall xDSL link maintenance functions are associated with the application dependent part.

Figure 8 shows the xDSL reference points and the scope of the OAM.

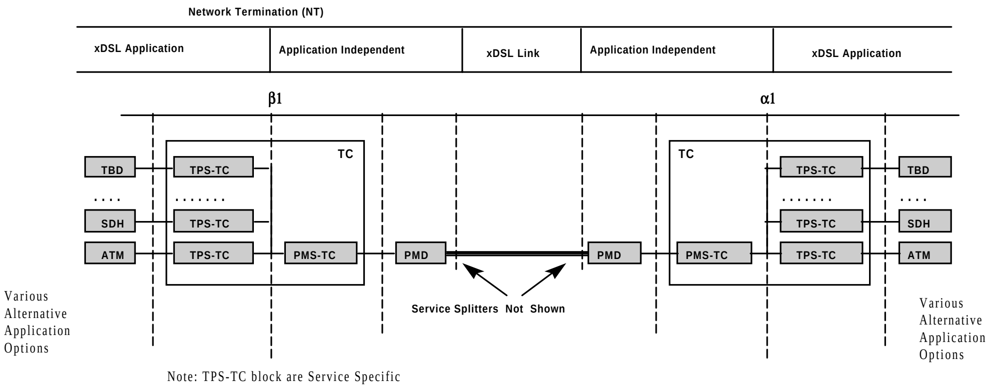


Figure 8: xDSL reference points and OAM scope

7.3 Transport requirements

7.3.1 General

For the transport of ATM on modems compliant with the ADSL and VDSL requirements, channels shall be independently set to any bit rate in accordance with those documents, up to the maximum aggregate capacity determined by the start-up process. In addition, for each channel the bit rates for the upstream and downstream directions may be set independently from each other.

7.3.2 Channelization

For ATM systems the channelization of different payloads is embedded within the ATM data stream using different Virtual Paths and/or Virtual Channels. Hence, the basic requirements for ATM are for at least one xDSL channel downstream and at least one xDSL upstream channel.

The xDSL specifications give the possibility to use both the "Interleaved" and "Fast" paths for services with requirements for either high error performance or low latency respectively. The real need for this dual nature for ATM services depends on the service/application profile, and is yet to be confirmed. Consequently, different configurations of xDSL access could be considered. More specifically, possibly three "latency classes" could be envisaged:

- single latency, not necessarily the same for each direction of transmission;
- dual latency downstream, single latency upstream;
- dual latency both upstream and downstream.

For the transport of only ATM over xDSL, all modems shall use the AS0 channel downstream and the LS0 channel upstream for the single latency class (see TS 101 270-1 [32]). Channels AS1 and LS1 are reserved for dual latency. The details of the dual latency option are for further study.

A "hybrid" implementation of one or more Bit Synchronous (Plesiochronous) channels together with the ATM channels is not precluded by the above. The bandwidth occupied by the Bit Synchronous channel shall first be reserved before allocating the remaining bandwidth to the ATM channel.

7.3.3 Information flows

7.3.3.1 Elemental information flows across the α and β interfaces

Five elemental information flows across the α and β interfaces are identified:

- data flow (α1 and β1);
- synchronization flow (α1 and β1);
- link control flow (α2 and β2);
- link performance and path characterization flow (α2 and β2);
- xDSL TPS-TC performance information flow (between LT and NT).

7.3.3.1.1 Data flow

The data flow shall be supported by one or two data pipes with different error protection properties and therefore different latency characteristics; it shall be byte oriented and the data shall be treated as unstructured by the application independent part.

7.3.3.1.2 Synchronization flow

This flow provides the means through which synchronization between the PMD level and the TC level is performed. The different considered items are:

- data (byte synchronization);
- network timing reference (downstream).

With the exception of Control and Performance parameter passing, synchronization flows are based on a fixed timing regime. Synchronization of Control and Performance Parameter passing is implied by a message transfer protocol.

Further study is required on this issue.

7.3.3.1.3 Link Control flow

The Link Control flow comprises all the relevant control, configuration and status messages for xDSL link. A non exhaustive list of Control Primitives is (common to both the α and β interfaces):

- activation;
- deactivation;
- alarms and anomalies (e.g. dying gasp);
- link status;
- synchronization status.

Control Parameters may include the Requested Data Rate, Link Status parameters and specific bandwidth allocation parameter (at the α interface).

7.3.3.1.4 Link Performance and Path Characterization flow

The Link Performance and Path Characterization flow provides all the relevant performance and physical characteristics of the VDSL link.

Performance Primitives typically report defects and errors (e.g. Loss of Signal, Loss of Frame, FEC anomalies etc.) and Performance Parameters include counts of errored blocks, CRC and FEC anomalies.

Typical Path Characterization Parameters are the line attenuation, the Signal to Noise Ratio (SNR) and the Return Loss.

Error detection shall be implemented as defined in ITU-T Recommendation I.432.1 [35] with the exception that any HEC error may be considered as a multiple bit error, and therefore HEC error correction shall not be performed.

7.3.3.1.4.1 Loopback for asymmetric xDSL

Loopback function at the physical layer of asymmetric xDSL is not feasible. Therefore, this function may be implemented only at the ATM Layer.

7.3.3.1.5 xDSL TPS-TC performance- Transport means

The application independent part shall provide means for transporting indication of remote anomalies detected in the TPS-TC (such as RLCD), not relying on the correct operation of the TPS-TC sub-layer.

These could by transported either by means of specific indicator bits or a specified clear channel (EOC).

E.g. the LCD-i (interleaved path) and LCD-ni (fast path) defects are mapped into the reserved indicator bits defined in ANSI T1.413 (table 14, subclause 6.2.1.1) [36], according to table 1.

Table 1: Mapping of reserved indicator bits for ADSL

Bit 14	Bit 15	Interpretation
1	1	notLCD-i and notLCD-ni
1	0	notLCD-i and LCD-ni
0	1	LCD-i and notLCD-ni
0	0	LCD-i and LCD-ni

7.3.3.2 Other Information flows

The use of ATM cell based transport may be used for specific management purposes such as:

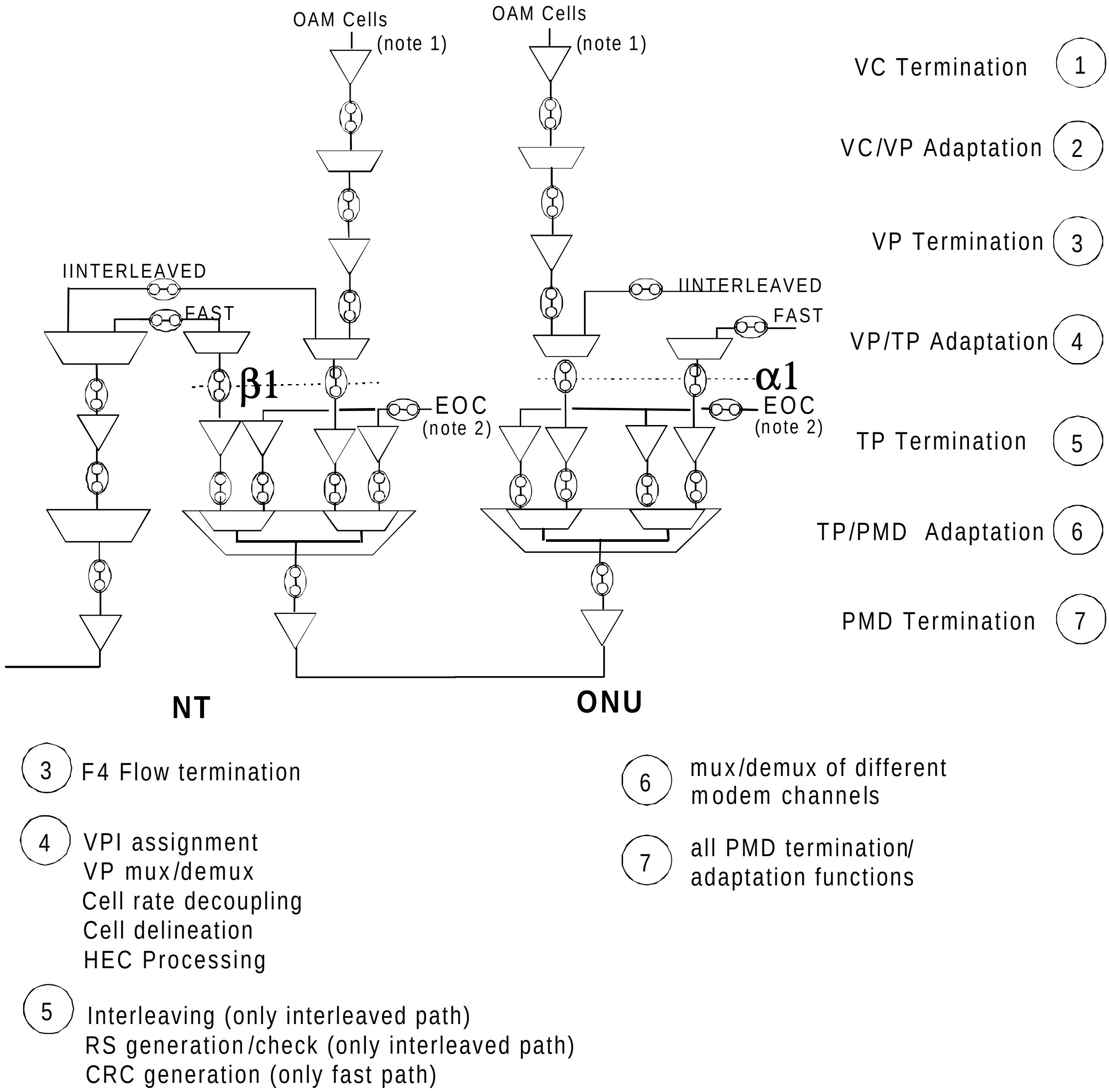
- ATM functions within the NT (related to ATM cell handling, e.g. buffer overflow, etc.) according to EN 301 163-1-1 [34];
- NT-UNI management function;
- optional terminal adaptation functions (as Ethernet interworking).

In order not to increase the complexity of the NT a single management cell approach has been suggested.

7.3.4 Protocols

With respect to the protocol reference model for B-ISDN, only the Physical Medium Dependent (PMD) and Transmission Convergence (TC) sublayers of the physical layer and the ATM layer are relevant to this subclause.

Figure 9 shows the protocol layers for the specific reference model given in figure 5. In this example, the T interface supports ATM. Non-ATM interfaces are also possible, but are not discussed in this subclause.



NOTE 1: OAM Cell stack might use fast or interveaved path, whatever appropriate.
NOTE 2: Only one EOC shall be carried either through the fast or interleaved channel.

Figure 9: Protocol layers

7.4 Quality of Service (QoS)

7.4.1 Data Rates

The data rates are defined in TS 101 270-1 [32] and ETR 328 [33]. Channel data rates can be set on a semi-permanent basis depending upon the line characteristics for the particular user. Complete flexibility is therefore given to the Network Operator.

7.4.2 BER

TS 101 270-1 [32] and ETR 328 [33] specify a BER of 10^{-7} with a 6 dB margin.

The Network Operator may decide on a BER/ Latency/ Range combination that meets the required service quality for the network.

The effect of xDSL performance impairments on ATM performance is for further study.

7.5 System Issues

For further study.

7.6 Description of functional blocks

7.6.1 Access Node ATM layer functions

In the downstream direction this block performs cell routing on a VPI and/or VCI basis to the appropriate xDSL modem and optionally to the "Fast" or "Interleaved" TC sublayer of that modem. In the upstream direction the cell streams are combined/concentrated to form a single ATM cell stream.

7.6.2 ATM Transport Protocol Specific Transmission Convergence (TPS-TC)

The ATM TPS-TC may be specific to the xDSL transport method (e.g. ADSL or VDSL).

7.6.2.1 ADSL ATM TPS-TC

The ADSL ATM TPS-TC shall based on the ITU-T Recommendation I.432.2 [37] frame based method using the $x^{43} + 1$ scrambler. With reference to ITU-T Recommendation I.432 series, no recommendation is made for the values of α and δ parameters as the choice of these values is not considered to affect interoperability. However, it should be noted that the use of the values suggested in ITU-T Recommendation I.432 could be inappropriate due to the particular transmission characteristics of xDSL system.

7.6.2.2 VDSL ATM TPS-TC

The VDSL ATM TPS-TC is for further study.

NOTE: The VDSL ATM TPS-TC should be the same as the ADSL ATM TPS-TC unless it is shown there are strong (e.g. performance) advantages which result from an alternative solution.

7.6.2.3 Other xDSL ATM TPS-TC

For further study.

Annex A (normative): TDMA-based ATM PON specification

A.1 Architecture of the optical access network

A.1.1 Network architecture

The optical section of an Access Network system could be either a point-to-point, active, or passive point-to-multipoint architecture. Figure A.1 shows the architectures considered, which range from Fibre to the Home (FTTH), through Fibre to the Building/Curb (FTTB/C) to Fibre to the Cabinet (FTTCab). The OAN is common to all architectures shown in figure A.1, hence commonality in this system has the potential to generate large world-wide volumes.

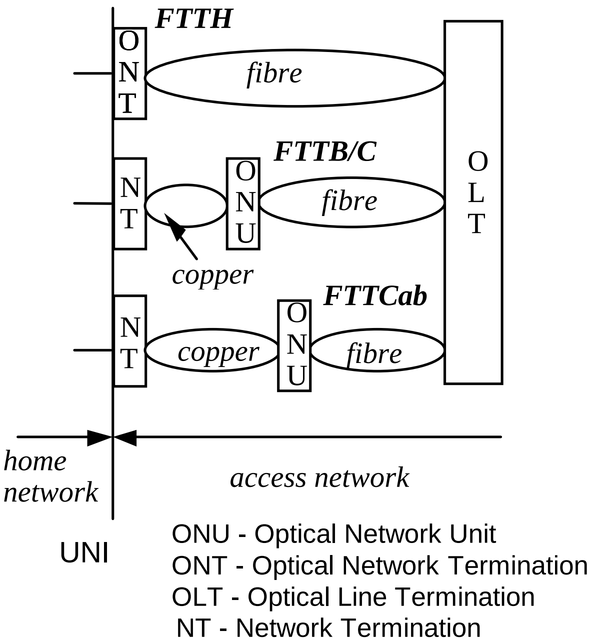


Figure A.1: Network Architecture

The FTTB/C and FTTCab network options are predominantly different only as a result of implementation, as a result they can be treated the same in the present document.

A.1.1.1 FTTCab/C/B Scenario

Within this scenario the following service categories have been considered:

- Asymmetric broadband services (e.g., digital broadcast services, VoD, Internet, distant learning, telemedicine, etc.).
- Symmetric broadband services (e.g., telecommunication services for small business customers, teleconsulting, etc.).
- PSTN and ISDN. The access network shall be able to provide in a flexible way narrowband telephone services as appropriate to the implementation.

A.1.1.2 FTTH Scenario

Fibre to the Home service drivers are similar to those of the previous scenarios and are motivated by the following factors:

- Indoor ONUs may be considered, resulting in more favourable environmental conditions.
- No change of intermediate ONU is required to upgrade access network capabilities to accommodate future evolution of broadband and multimedia services.
- Maintenance is easier, because it requires maintenance only for fibre systems, and all-fibre systems are regarded as more reliable than hybrid fibre-metallic ones.
- FTTH is a driver for the development of advanced optoelectronics technologies. The greater volume in production of optical modules will also accelerate the reduction in cost.

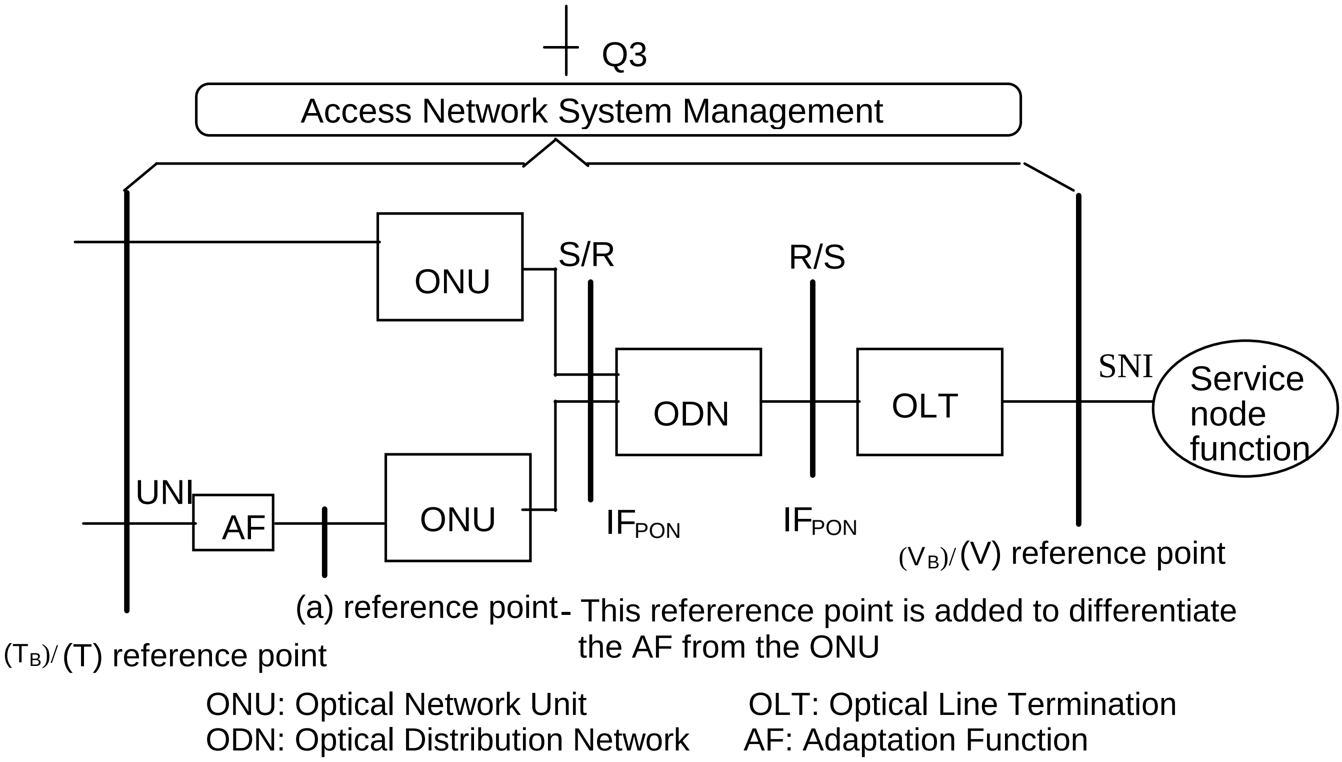
When these factors can be fully exploited they counterbalance a slightly higher per line cost. In that situation the FTTH scenario is regarded as economically feasible even in the short term.

A.1.2 Reference configuration

The reference configuration stems from ITU-T Recommendation G.982 [38] and is shown in figure A.2.

The ODN offers one or more optical paths between one OLT and one or more ONUs. Each optical path is defined between reference points S and R in a specific wavelength window. The two directions for optical transmission in the ODN are identified as follows:

- downstream direction for signals travelling from the OLT to the ONU(s);
- upstream direction for signals travelling from the ONU(s) to the OLT.



S/R: point on the optical fibre just after the OLT[Downstream]/ONU[Upstream] optical connection point (i.e. optical connector or optical splice).

R/S: point on the optical fibre just before the ONU[Downstream]/OLT[Upstream] optical connection point (i.eoptical connector or optical splice).

Figure A.2: Reference Configuration for an ATM based PON

This subclause describes the reference architecture for supporting ATM over a PON. This system consists of Optical Line Terminal (OLT), Optical Network Unit (ONU) and fibre cable which has a Passive Optical Network (PON) configuration. One fibre is passively split between multiple ONUs which share the capacity of one fibre. Because of the passive splitting, special actions are required with respect to privacy and security. Moreover, in the upstream direction a Medium Access Control (MAC) protocol is required to avoid collision of upstream data.

A.1.2.1 Service Node Interface

See ITU-T Recommendation G.902 [1].

A.1.2.2 Interfaces at the reference points S/R and R/S

The interface at these reference points is defined as the IF_{PON} interface. This is a PON-specific interface that supports all the protocol elements necessary to allow transmission between OLT and ONUs.

A.1.3 Functional blocks

A.1.3.1 Optical Line Termination

The Optical Line Termination (OLT) interface is over the SNI to service nodes, and to the PON. The OLT is responsible for managing all the PON specific aspects of the ATM transport system, and together with the ONU is responsible for providing transparent ATM transport service between the UNIs and the SNI over the PON.

A.1.3.2 Optical Network Unit

The Optical Network Unit (ONU) interfaces over the IF_{PON} to the OLT, and to the UNI. Together with the OLT, the ONU is responsible for providing transparent ATM transport service between the UNI and the SNI.

In this architecture, the ATM transport protocols at an IF_{PON} are described as consisting of physical medium dependent layer, transmission convergence layer, and ATM layer. This architecture is only intended to address the transport of ATM; further detail is contained in ITU-T Recommendation I.732 [39].

The physical medium dependent layer would include the modulation schemes for both the upstream and down stream channels (they may be different). It may be possible for the specification to allow for more than one type of Physical Medium Dependent Layer in a single direction.

The transmission convergence layer will be responsible for managing the distributed access to the upstream PON resource across the multiple ONUs. This is a key protocol element and will directly affect the resulting ATM QoS.

The ATM protocols should see no change in the way they operate over the PON. Within both the OLT and the ONU, the functions perform at the ATM layer at both an OLT and ONU would include cell relaying.

A.1.4 ONU functional block

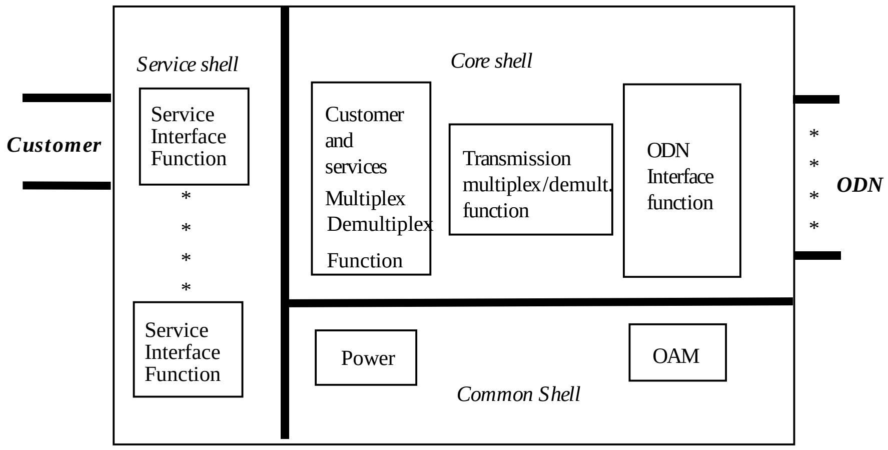


Figure A.3: Example of ONT functional blocks

Figure A.3 shows an example of an ONU in the case of FTTH. In this case the ONU is termed an ONT. The ONT is active and decouples the access network delivery mechanism from the in-house distribution. The ONT functions include: an ODN interface function; service interface function(s); transmission multiplexing/demultiplexing functions; customer and services multiplexing/demultiplexing functions, and powering.

A.1.4.1 Optical Distribution Network interface

The ODN interface function handles the opto-electronic conversion process. The ODN interface function extracts ATM cells from the downstream PON payload and inserts ATM cells into the upstream PON payload based on synchronization acquired from the downstream frame timing.

A.1.4.2 Multiplexing

A multiplexer (MUX) function multiplexes traffic from the service interfaces towards the ODN interface. Only valid ATM cells can be passed through the MUX, so many VPs can share the assigned upstream bandwidths effectively.

A.1.4.3 Service interface

The service interface function supports an interface over the UNI to an ATM terminal. The service interface function may handle the insertion of ATM cells into the upstream payload and extraction of ATM cells from the downstream payload.

A.1.4.4 Optical Network Unit Powering

For further study.

A.1.5 Optical Line Termination functional block

The OLT is connected to the switched networks via standardized interfaces (VB5.x, V5.x [6] to [9]). At the distribution side, it presents optical accesses according to the agreed requirements, in terms of bit rate, power budget, etc.

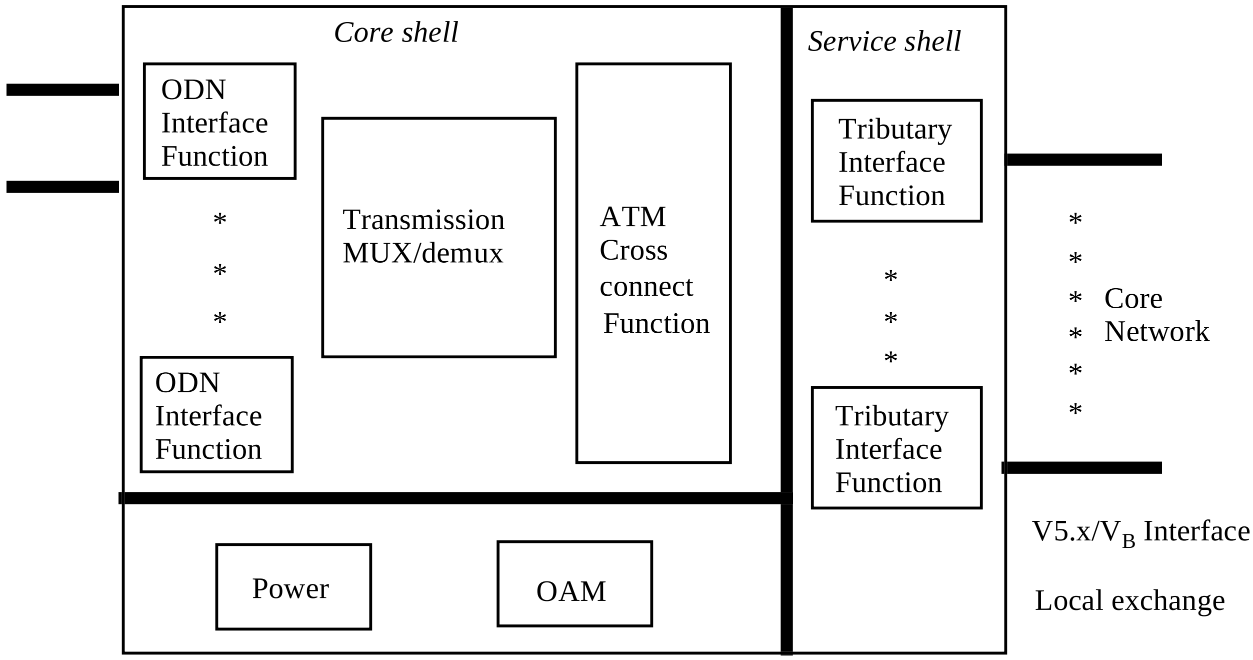


Figure A.4: Example of OLT Functional Blocks

Figure A.4 shows an example of the functional blocks in an OLT. The OLT includes tributary interface functions, ODN interface functions and multiplexing/demultiplexing functions for VP grooming. This combination is not intended to preclude Virtual Channel (VC) layer functions in the OLT. VC layer functions are for further study.

A.1.5.1 Tributary interface function

The tributary interface functions interface to one or more service nodes. The tributary interface function may handle the insertion of ATM cells into the upstream SDH payload and the extraction of ATM cells from the downstream SDH payload. Individual tributary interface functions may be duplicated, in which case a protection switching function is necessary.

A.1.5.2 MUX

The MUX function provides VP connections between the tributary interface function and the ODN interface function. Information such as user plane data, signalling and OAM flows are exchanged by using VCs of the VP.

A.1.5.3 ODN interface

The ODN interface function handles the opto-electronic conversion process. The ODN interface function handles the insertion of ATM cells into the downstream PON payload and the extraction of ATM cells from the upstream PON payload.

A.1.6 ODN functional block

In general, the ODN provides the optical transmission medium for the physical connection of the ONUs to the OLTs. Individual ODNs may be combined and extended through the use of optical amplifiers (ITU-T Recommendation G.982 [38]).

A.1.6.1 Passive optical elements

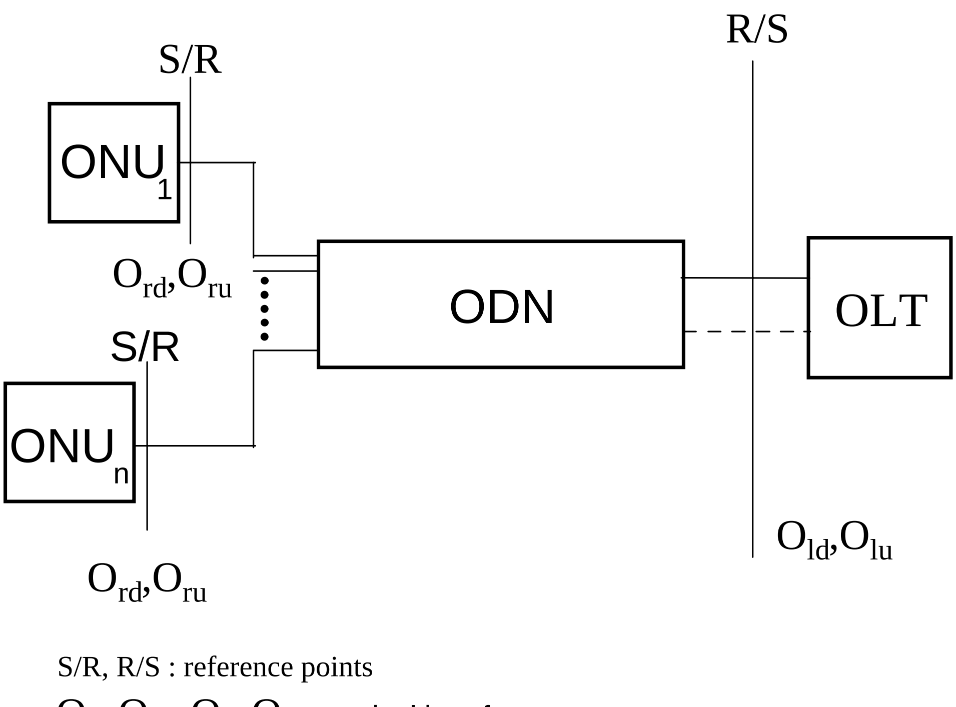
The ODN may include passive optical elements such as:

- single-mode optical fibres and cables;
- optical fibre ribbons and ribbon cables;
- optical connectors;
- passive branching components;
- passive optical attenuators;
- splices.

Passive optical components are described in ITU-T Recommendation G.671 [40]. Optical fibres and cables are described in ITU-T Recommendation G.652 [41].

A.1.6.2 Optical Interfaces

In the context of the reference configuration figure A.5 shows the generic physical configuration of an ODN.



S/R, R/S : reference points

O_{rd},O_{ru}, O_{ld},O_{lu} : optical interfaces

bold solid lines represent one or more fibres;

dashed lines represent optional protection fibres

Figure A.5: Generic physical configuration of the Optical Distribution Network

The two directions for optical transmission in the ODN are identified as follows:

- *downstream* direction for signals travelling from the OLT to the ONU(s);
- *upstream* direction for signals travelling from the ONU(s) to the OLT.

Transmission in downstream and upstream directions can take place on the same fibre and components (duplex/diplex working) or on separate fibres and components (simplex working).

If additional connectors or other passive devices are needed for ODN rearrangement, they shall be located between S and R and their losses shall be taken into account in any optical loss calculation.

The ODN offers one or more optical paths between one OLT and one or more ONUs. Each optical path is defined between reference points in a specific wavelength window.

The following optical interfaces are defined in figure A.5:

O_{ru}, O_{rd}: optical interface at the reference point S/R between the ONU and the ODN for the upstream and downstream directions respectively.

O_{lu}, O_{ld}: optical interfaces at the reference point R/S between the OLT and the ODN for the upstream and downstream directions respectively.

At the physical layer, the interfaces may require more than one fibre, e.g. for separation of transmission directions or different types of signals (services).

Specifications of the optical interfaces (O_{ru}, O_{rd}, O_{lu}, O_{ld}) are defined in clause A.2.

The optical properties of the ODN shall enable the provision of any presently foreseeable service, without the need of extensive modifications to the ODN itself. This requirement has an impact on the properties of the passive optical components which constitute the ODN. A set of essential requirements, which have a direct influence on the optical properties of the ODN, are identified as follows:

- *optical wavelength transparency*: devices, such as optical branching devices, which are not intended to perform any wavelength-selective function, shall be able to support transmission of signals at any wavelength in the 1 310 nm and 1 550 nm regions;
- *reciprocity*: reversal of input and output ports shall not cause significant changes of the optical loss through the devices;
- *fibre compatibility*: all optical components shall be compatible with single-mode fibre as specified in ITU-T Recommendation G.652 [41].

A.1.6.2.1 Optical Distribution Network model loss calculations

This is described in ITU-T Recommendation G.982 [38].

A.1.6.2.2 Optical Distribution Network model loss calculation technique

This is described in ITU-T Recommendation G.982 [38].

A.2 Optical network requirements

A.2.1 Layered structure of optical network

Layering is based on ITU-T Recommendation G.982 [38].

The ODN refers to the fibre distribution network based on passive optical splitters, or branching components. The OAN is the system between the "V" and "T" reference points. The ONU may have an Adaptation Function (AF), for Digital Subscriber Line (DSL) transmission over copper to the customer. The OAN is managed as one element, through a Q3 management interface.

The protocol reference model is divided into physical media, section, and path layers as in the ITU-T Recommendations G.902 [1], I.326 [42], G.982 [38]; an example for an ATM-PON shown in table A.1. In the ATM-PON network, the path layer corresponds to the VP of the ATM layer.

The section layer is divided into PON transmission and adaptation sublayers, which correspond to the transmission convergence sub-layer of the B-ISDN in ITU-T Recommendation I.321 [43]. The PON transmission sublayer terminates the required transmission function on the ODN. The PON specific functions are terminated by the PON transmission sublayer, and it is not seen from the adaptation sublayer.

Table A.1: Layered Structure of ATM-PON Network

<table>
<tr><td colspan="3">Path layer</td><td>See ITU-T Recommendation I.732 [39]</td></tr>
<tr><td rowspan="3">Transmission medium layer (see note)</td><td rowspan="2">TC layer</td><td>Adaptation</td><td>See ITU-T Recommendation I.732 [39]</td></tr>
<tr><td>PON transmission</td><td>Ranging
Cell slot allocation
Bandwidth allocation
Privacy and security
Frame alignment
Burst synchronization
Bit/byte synchronization</td></tr>
<tr><td colspan="2">Physical medium layer</td><td>E/O adaptation
Wavelength division multiplexing
Fibre connection</td></tr>
<tr><td colspan="4">NOTE: The transmission medium layer shall provide the related OAM functions.</td></tr>
</table>

The two layers considered are the physical medium dependent layer and the section layer, based on ITU-T Recommendation G.958 [44] layering principles.

A.2.2 Physical medium dependent layer requirements for the ATM-PON

A.2.2.1 Digital signal nominal bit rate

The transmission line rate shall be a multiple of 8 kHz. The target standardized system will have the following nominal line rates:

Option 1: Symmetric 155,52 Mbit/s for FTTCab /C/B/H.

Option 2: Asymmetric 155,52 Mbit/s upstream / 622,08 Mbit/s downstream for FTTCab/C/B.

Parameters to be defined are categorized by downstream and upstream, and nominal bit rate as shown in table A.2.

Table A.2: Relation between Parameter Categories and Tables

Transmission direction	Nominal bit rate	Table
Downstream	155,52 Mbit/s	Table A.4
	622,08 Mbit/s	Table A.5
Upstream	155,52 Mbit/s	Table A.6

All parameters are specified as follows, and shall be in accordance with tables A.3 to A.6. There are 4 kinds of ONUs and they are distinguished by bit rates of 155,52 Mbit/s and 622,08 Mbit/s and by optical path loss of Class B and Class C. The terms Class B and Class C are defined in ITU-T Recommendation G.982 [38].

All parameter values specified are worst-case values, assumed to be met over the range of standard operating conditions (i.e. temperature and humidity ranges), and they include ageing effects. The parameters are specified relative to an optical section design objective of a Bit Error Ratio (BER) not worse than 1×10^{-10} for the extreme case of optical path attenuation and dispersion conditions.

A.2.2.2 Physical media and transmission method

A.2.2.2.1 Transmission medium

This specification is based on the fibre described in ITU-T Recommendation G.652 [41].

A.2.2.2.2 Transmission direction

The signal is transmitted both upstream and downstream through the transmission medium.

A.2.2.2.3 Transmission methodology

Bi-directional transmission is accomplished by use of either a Wavelength Division Multiplexing (WDM) technique, employing wavelengths in the 1 310 nm region and 1 550 nm on a single fibre, or unidirectional transmission on each of two fibres (simplex transmission) in the 1 310 nm wavelength region.

A.2.2.3 Bit rate

A.2.2.3.1 Downstream

The nominal bit rate of the interface is 155,52 Mbit/s or 622,08 Mbit/s. The accuracy is ± 4,6 ppm.

A.2.2.3.2 Upstream

The nominal bit rate of the interface is 155,52 Mbit/s. The accuracy is ± 4,6 ppm.

A.2.2.4 Line code

A.2.2.4.1 Downstream

NRZ coding.

Scrambling method is defined in TC layer specification.

Convention used for optical logic level is:

- high level of light emission for a binary ONE;
- low level of light emission for a binary ZERO.

A.2.2.4.2 Upstream

NRZ coding.

Scrambling method is defined in TC layer specification.

Convention used for optical logic level is:

- high level of light emission for a binary ONE;
- low level of light emission for a binary ZERO.

A.2.2.5 Operating wavelength

A.2.2.5.1 Downstream direction

The operating wavelength range for the downstream direction on single fibre systems shall be 1 480 nm to 1 580 nm.

The operating wavelength range for the downstream direction on two fibre systems shall be 1 260 nm to 1 360 nm.

A.2.2.5.2 Upstream direction

The operating wavelength range for the upstream direction shall be 1 260 nm to 1 360 nm.

A.2.2.6 Transmitter at O_{ld} and O_{ru}

All parameters are specified as follows, and shall be in accordance with tables A.4 to A.6.

A.2.2.6.1 Source type

Depending on attenuation/dispersion characteristics, feasible transmitter devices include Multi-Longitudinal Mode (MLM) lasers and Single-Longitudinal Mode (SLM) lasers. For each of the applications, this specification indicates a nominal source type. It is understood that the indication of a nominal source type in this specification is not a requirement and that SLM devices can be substituted for any application showing MLM as the nominal source type without any degradation of system performance.

A.2.2.6.2 Spectral characteristics

For MLM lasers, spectral width is specified by the maximum Root-Mean-Square (RMS) width under standard operating conditions. The RMS width is understood to mean the standard deviation of the spectral distribution. The measurement method for RMS widths should take into account all modes which are not more than 20 dB down from the peak mode.

For the SLM lasers, the maximum spectral width is specified by the maximum full width of the central wavelength peak, measured 20 dB down from the maximum amplitude of the central wavelength under standard operating conditions. Additionally, for control of mode partition noise in SLM systems, a minimum value for the laser side-mode suppression ratio is specified.

A.2.2.6.3 Mean launched power

The mean launched power at O_{ld} and O_{ru} is the average power of a pseudo-random data sequence coupled into the fibre by the transmitter. It is given as a range to allow for some cost optimization and to cover all allowances for operation under standard operating conditions, transmitter connector degradation, measurement tolerances, and ageing effects.

The lower figure is the minimum power which shall be provided under all circumstances and the higher one is the power which shall never be exceeded.

For accuracy of measurement, special care should be taken to account for the burst mode signal output from ONU.

A.2.2.6.3.1 Launched optical power without input to the transmitter

In the upstream direction, the ONU transmitter shall launch no power into the fibre in all slots which are not assigned to that ONU. The ONU shall also launch no power during the Guard time of slots that are assigned to it with the exception of the last two bits which may be used for laser pre-bias, and the bit immediately following the assigned cell, during which the output falls to zero. The launched power level during laser pre-bias shall be less than 0,1 of the one level.

A.2.2.6.4 Minimum extinction ratio

The convention adopted for optical logic level is:

- high level of light emission for a logical "1";
- low level of light emission for a logical "0".

The extinction ratio (EX) is defined as:

$$EX=10 \log_{10} (A/B)$$

where A is the average optical power level at the centre of the logical "1" and B is the average optical power level at the centre of the logical "0".

The extinction ratio for the upstream direction burst mode signal is applied from the first bit of the preamble to the last bit of the burst signal inclusive. This does not apply to the optical power setup procedure (see A.2.4.4.2, "Ranging procedure in the ONU").

A.2.2.6.5 Maximum reflectance of equipment, measured at transmitter wavelength

Reflections from equipment (ONU/OLT) back to the cable plant are specified by the maximum permissible reflectance of the equipment measured at O_{ld}/O_{ru}. It shall be in accordance with tables A.4 to A.6.

A.2.2.6.6 Mask of transmitter eye diagram

In this specification, general transmitter pulse shape characteristics including rise time, fall time, pulse overshoot, pulse undershoot, and ringing, all of which should be controlled to prevent excessive degradation of the receiver sensitivity are specified in the form of a mask of the transmitter eye diagram at O_{ld}/O_{ru}. For the purpose of an assessment of the transmit signal, it is important to consider not only the eye opening, but also the overshoot and undershoot limitations.

A.2.2.6.6.1 OLT transmitter

The parameters specifying the mask of the eye diagram are shown in figure A.6.

A.2.2.6.6.2 ONU transmitter

The parameters specifying the mask of the eye diagram are shown in figure A.7.

The mask of the eye diagram for the upstream direction burst mode signal is applied from the first bit of the preamble to the last bit of the burst signal inclusive. This does not apply to the optical power setup procedure (see A.2.4.4.2, "Ranging procedure in the ONU").

A.2.2.6.7 Tolerance to the reflected optical power

The specified transmitter performance shall be met in the presence at S of the optical reflection level specified in tables A.4 to A.6.

A.2.2.7 Optical path between O_{ld}/O_{ru}

A.2.2.7.1 Attenuation range

Two classes of attenuation ranges are being specified as defined in ITU-T Recommendation G.982 [38]:

10 dB to 25 dB: Class B

15 dB to 30 dB: Class C

Attenuation specifications are assumed to be worst-case values including losses due to splices, connectors, optical attenuators (if used) or other passive optical devices, and any additional cable margin to cover allowances for:

1) future modifications to the cable configuration (additional splices, increased cable lengths, etc.);
2) fibre cable performance variations due to environmental factors; and
3) degradation of any connector, optical attenuators (if used) or other passive optical devices between points S and R, when provided.

A.2.2.7.2 Minimum optical return loss of the cable plant at point R/S, including any connectors

Overall minimum Optical Return Loss (ORL) specification at point R/S in the ODN shall be better than 32 dB.

Optionally, the minimum ORL specification at point S in the ODN shall be better than 19 dB. Annex B expresses the optional cases.

NOTE: The overall reflectance at the S/R point for an ODN model is dominated by the optical connectors at the ODF. The maximum reflectance of a single discrete element within ITU-T Recommendation G.982 [38] is -35 dB. The reflectance from the two ODF connectors leads to a figure of -32 dB. However, based on another network model, the overall reflectance may become worse than -2 dB.

A.2.2.7.3 Maximum discrete reflectance between points S and R

All discrete reflectances in the ODN shall be better than -35 dB as defined in ITU-T Recommendation G.982 [38].

A.2.2.7.4 Dispersion

Systems considered limited by dispersion have maximum values of dispersion (ps/nm) specified in tables A.4 to A.6. These values are consistent with the maximum optical path penalties specified. They take into account the specified transmitter type, and the fibre dispersion coefficient over the operating wavelength range.

Systems considered limited by attenuation do not have maximum dispersion values specified and are indicated in tables A.4 to A.6 with the entry "NA" (not applicable).

A.2.2.8 Receiver at reference O_{rd} and O_{lu}

All parameters are specified as follows, and shall be in accordance with tables A.4 to A.6.

A.2.2.8.1 Minimum sensitivity

Receiver sensitivity is defined as the minimum acceptable value of average received power at point R to achieve 10^{-10} BER. It takes into account power penalties caused by use of a transmitter under standard operating conditions with worst-case values of extinction ratio, pulse rise and fall times, optical return loss at point S, receiver connector degradation and measurement tolerances. The receiver sensitivity does not include power penalties associated with dispersion, jitter, or reflections from the optical path; these effects are specified separately in the allocation of maximum optical path penalty. Ageing effects are not specified separately since they are typically a matter between a network provider and an equipment manufacturer.

A.2.2.8.2 Minimum overload

Receiver overload is the maximum acceptable value of the received average power at point R for a 10^{-10} BER.

A.2.2.8.3 Maximum optical path penalty

The receiver is required to tolerate an optical path penalty not exceeding 1 dB to account for total degradations due to reflections, intersymbol interference, mode partition noise, and laser chirp.

A.2.2.8.4 Maximum reflectance of receiver equipment, measured at receiver wavelength

Reflections from the equipment (ONU/OLT) back to the cable plant are specified by the maximum permissible reflectance of the equipment measured at O_{rd} and O_{lu}. It shall be in accordance with tables A.4 to A.6.

A.2.2.8.5 Differential optical path loss

Differential optical path loss means the optical path loss difference between the highest and lowest optical path loss in the same ODN. The maximum differential optical path loss should be 15 dB.

A.2.2.8.6 Clock extraction capability

NOTE: The clock of the upstream transmission signal is extracted rapidly from several bits alternating continuous code (preamble) of the positive logic "1", "0". The clock extracted from the preamble is maintained at least during receiving signal from the delimiter through the end of the upstream cell, or is continuously extracted from the signal after the preamble during receiving the cell.

A.2.2.8.7 Jitter performance

This subclause deals with jitter requirements for optical interfaces at the ATM-PON.

A.2.2.8.7.1 Jitter transfer

The jitter transfer specification applies only to the ONU.

$$\textit{jitter transfer} = 20\log_{10}\left[\frac{\textit{jitter on upstream signal UI}}{\textit{jitter on downstream signal UI}} \bullet \frac{\textit{downstream bit rate}}{\textit{upstream bit rate}}\right]$$

The jitter transfer function of an ONU shall be under the curve given in figure A.8, when input sinusoidal jitter up to the mask level in figure A.9 is applied, with the parameters specified in this figure for each bit rate.

A.2.2.8.7.2 Jitter tolerance

Jitter tolerance is defined as the peak-to-peak amplitude of sinusoidal jitter applied on the input ATM-PON signal that causes a 1 dB optical power penalty at the optical equipment. Note that it is a stress test to ensure that no additional penalty is incurred under operating conditions.

ONU shall tolerate, as a minimum, the input jitter applied according to the mask in figure A.9, with the parameters specified in this figure for each bit rate.

A.2.2.8.7.3 Jitter generation

Jitter generation specification applies only to ONU.

An ONU shall not generate more than 0,02 UI RMS jitter, with no jitter applied to the downstream input and with a measurement bandwidth of 1,3 MHz.

A.2.2.8.8 Consecutive identical digit immunity

The specific test patterns are made up of consecutive blocks of data of four types:

A) all 1 s (zero timing content, high average signal amplitude);

B) pseudo-random data with a mark-density ratio of 1/2;

C) all 0 s (zero timing content, low average signal amplitude);

D) a data block consisting of the ATM overhead bytes.

The test pattern is a sequence of data blocks consisting of D, A, B, D, C, and B. The duration of the zero-timing-content periods A and C is made equal to the longest like-element sequences. CID immunity is defined as this duration.

A.2.2.8.9 Tolerance to reflected power

The tolerance to reflected power is the allowable ratio of optical input average power of O_{rd} and O_{lu} to reflected optical average power when multiple reflected light is regarded as a noise light at O_{rd} and O_{lu} respectively.

The tolerance to reflected power is defined at minimum receiving sensitivity.

A.2.2.8.10 Transmission quality and error performance

For designing a frame structure, robustness of the overhead bytes for transmission bit errors of around 10^{-6} should be considered to avoid system down or failures. Error characteristics of the optical physical medium dependent layer in the local field environment should be considered whether any error correction mechanism is required or not for the overhead bytes at the section level.

The average transmission quality should have a very low bit error rate of less than 10^{-9} across the entire PON system. An objective error rate required for optical components should be better than 10^{-10} in the environment conditions as defined in ITU-T Recommendation G.957 [45].

Table A.3: Physical medium dependent layer parameters of ODN

Items	Unit	Specification
Fibre type	-	ITU-T Recommendation G.652 [41]
Attenuation range	dB	Class B: 10 - 25 Class C: 15 - 30
Differential optical path loss	dB	15
Maximum optical path penalty	dB	1
Max differential logical reach	km	20
Maximum fibre distance between S/R and R/S points	km	20
Minimum supported split ratio	-	Restricted by path loss and ONU addressing limits. PON with passive splitters (16 or 32 way split)
Bi-directional transmission	-	1-fibre WDM or 2-fibre
Maintenance wavelength	nm	to be defined

Table A.4: Optical interface parameters of 155 Mbit/s downstream direction

Items	Unit	Single Fibre		Dual Fibre	
		OLT Transmitter (optical interface Old)			
Nominal bit rate	Mbit/s	155,52		155,52	
Operating wavelength	nm	1 480 - 1 580		1 260 - 1 360	
Line code	-	Scrambled NRZ		Scrambled NRZ	
Mask of the transmitter eye diagram	-	Figure A.6		Figure A.6	
Maximum reflectance at transmitter wavelength	dB	N.A.		N.A.	
minimum ORL of ODN at point R/S	dB	more than 32		more than 32	
Mean launched power MIN Class B/C	dBm	-4/-2		-4/-2	
Mean launched power MAX Class B/C	dBm	+2/+4		+1/+3	
Launched optical power without input to the transmitter	dBm	N.A.		N.A.	
Extinction ratio	dB	more than 10		more than 10	
Tolerance to the transmitter incident light power	dB	more than -15		more than -15	
Nominal source type	-	MLM	SLM	MLM	SLM
Maximum RMS width	nm	1,8	-	5,8	-
Maximum -20 dB width	nm	-	1	-	1
Minimum side mode suppression ratio	dB	-	30	-	30
		ONU Receiver (optical interface Ord)			
Maximum reflectance at receiver wavelength	dB	less than -20		less than -20	
Bit error ratio	-	less than 10^{-10}		less than 10^{-10}	
Minimum sensitivity Class B/C	dBm	-30/-33		-30/-33	
Minimum overload Class B/C	dBm	-8/-11		-9/-12	
Consecutive identical digit immunity	bit	more than 72		more than 72	
Jitter transfer	-	Figure A.8		Figure A.8	
Jitter tolerance	-	Figure A.9		Figure A.9	
Jitter generation in 1,3 MHz bandwidth	UI RMS	0,02		0,02	
Tolerance to the reflected optical power	dB	less than 10		less than 10	

Table A.5: Optical interface parameters of 622 Mbit/s downstream direction

Items	Unit	Single Fibre		Dual Fibre	
		OLT Transmitter (optical interface Old)			
Nominal bit rate	Mbit/s	622,08		622,08	
Operating wavelength	nm	1 480 - 1 580		1 260 - 1 360	
Line code	-	Scrambled NRZ		Scrambled NRZ	
Mask of the transmitter eye diagram	-	Figure A.6		Figure A.6	
Maximum reflectance at transmitter wavelength	dB	N.A.		N.A.	
minimum ORL of ODN at point R/S	dB	more than 32		more than 32	
Mean launched power MIN Class B/C	dBm	-2/-2		-2/-2	
Mean launched power MAX Class B/C	dBm	+4/+4		+3/+3	
Launched optical power without input to the transmitter	dBm	N.A.		N.A.	
Extinction ratio	dB	more than 10		more than 10	
Tolerance to the transmitter incident light power	dB	more than -15		more than -15	
Nominal source type	-	MLM	SLM	MLM	SLM
Maximum RMS width	nm	-	-	1,4	-
Maximum -20 dB width	nm	-	1	-	1
Minimum side mode suppression ratio	dB	-	30	-	30
		ONU Receiver (optical interface Ord)			
Maximum reflectance at receiver wavelength	dB	less than -20		less than -20	
Bit error ratio	-	less than 10^{-10}		less than 10^{-10}	
Minimum sensitivity Class B/C	dBm	-28/-33		-28/-33	
Minimum overload Class B/C	dBm	-6/-11		-7/-12	
Consecutive identical digit immunity	bit	more than 72		more than 72	
Jitter transfer	-	Figure A.8		Figure A.8	
Jitter tolerance	-	Figure A.9		Figure A.9	
Jitter generation in 1,3 MHz bandwidth	UI RMS	0,02		0,02	
Tolerance to the reflected optical power	dB	less than 10		less than 10	

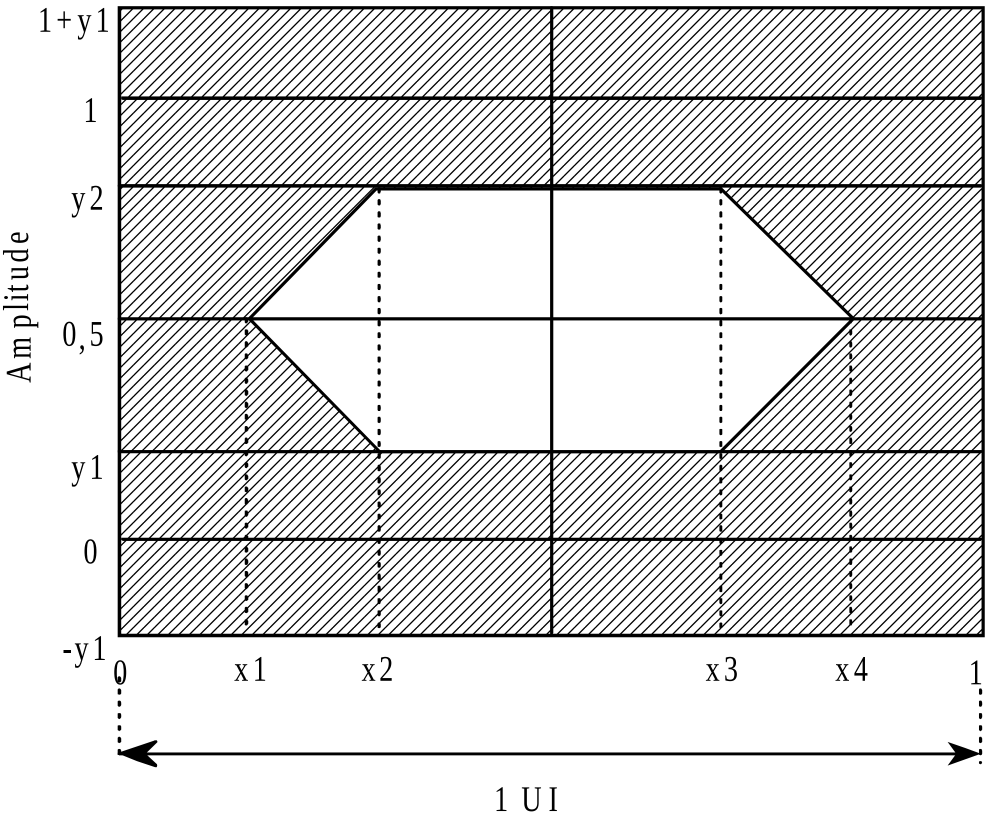
Table A.6: Optical interface parameters of 155 Mbit/s upstream direction

Items	Unit	Single Fibre		Dual Fibre	
		ONU Transmitter (optical interface Oru)			
Nominal bit rate	Mbit/s	155,52		155,52	
Operating wavelength	nm	1 260 - 1 360		1 260 - 1 360	
Line code	-	Scrambled NRZ		Scrambled NRZ	
Mask of the transmitter eye diagram	-	Figure A.7		Figure A.7	
Maximum reflectance at transmitter wavelength	dB	less than -6		less than -6	
minimum ORL of ODN at point R/S	dB	more than 32		more than 32	
Mean launched power MIN Class B/C	dBm	-4/-2		-4/-2	
Mean launched power MAX Class B/C	dBm	+2/+4		+1/+3	
Launched optical power without input to the transmitter	dBm	less than Min sensitivity -10		less than Min sensitivity -10	
Extinction ratio	dB	more than 10		more than 10	
Tolerance to the transmitter incident light power	dB	more than -15		more than -15	
Nominal source type	-	MLM	SLM	MLM	SLM
Maximum RMS width	nm	5,8	-	5,8	-
Maximum -20 dB width	nm	-	1	-	1
Minimum side mode suppression ratio	dB	-	30	-	30
		OLT Receiver (optical interface Olu)			
Maximum reflectance at receiver wavelength	dB	less than -20		less than -20	
Bit error ratio	-	less than 10^{-10}		less than 10^{-10}	
Minimum sensitivity Class B/C	dBm	-30/-33		-30/-33	
Minimum overload Class B/C	dBm	-8/-11		-9/-12	
Consecutive identical digit immunity	bit	more than 72		more than 72	
Jitter transfer	-	N.A.		N.A.	
Jitter tolerance	-	N.A.		N.A.	
Jitter generation in 1,3 MHz bandwidth	UI RMS	N.A.		N.A.	
Tolerance to the reflected optical power	dB	less than 10		less than 10	

NOTE 1: Values of Maximum -20 dB width, and Minimum side mode suppression ratio are referred to ITU-T Recommendation G.957 [45].

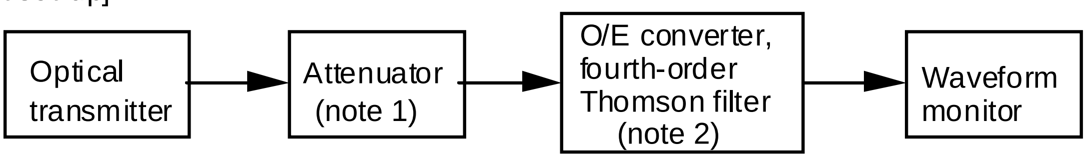
NOTE 2: The value of "minimum ORL of ODN at point S" should be more than 19 dB in optional cases which are described in annex B.

NOTE 3: The values of ONU transmitter reflectance for case that the value of "minimum ORL of ODN at point S" is 19 dB are described in annex C.



	155,52 Mb/s	622,08 Mb/s
x1/x4	0,15/0,85	0,25/0,75
x2/x3	0,35/0,65	0,40/0,60
y1/y2	0,20/0,80	0,20/0,80

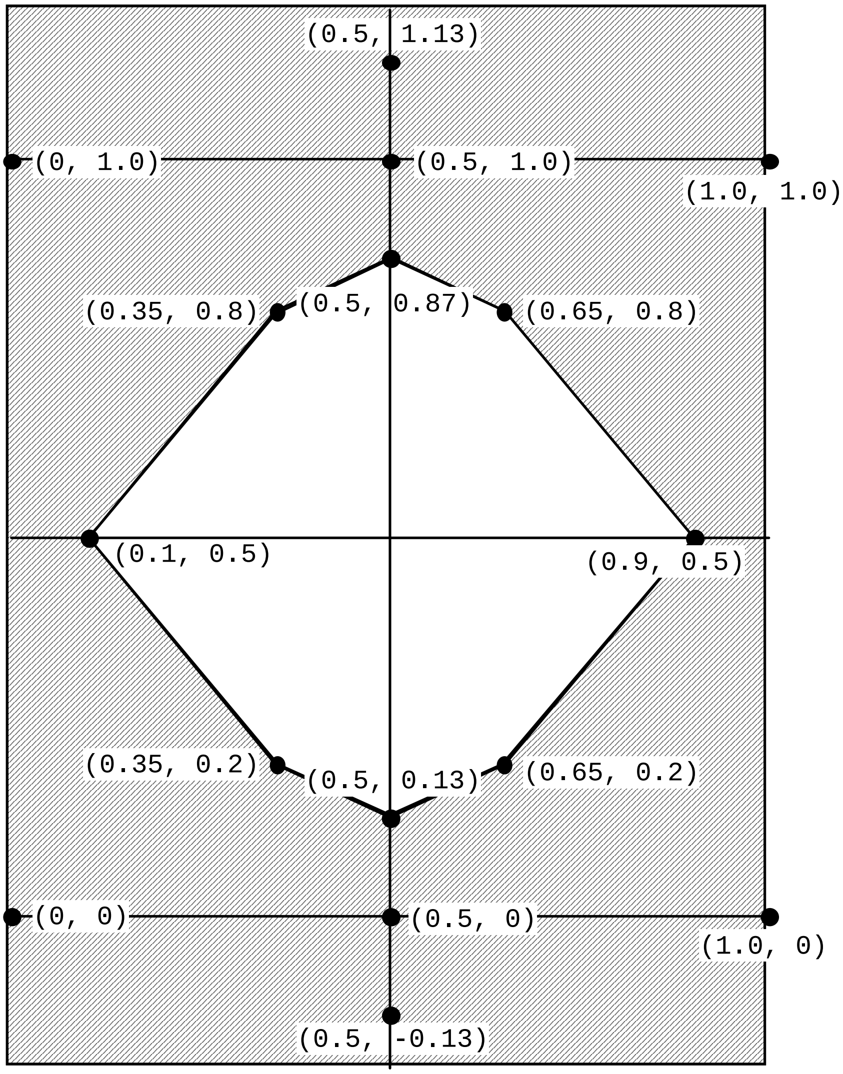
[Test set-up]



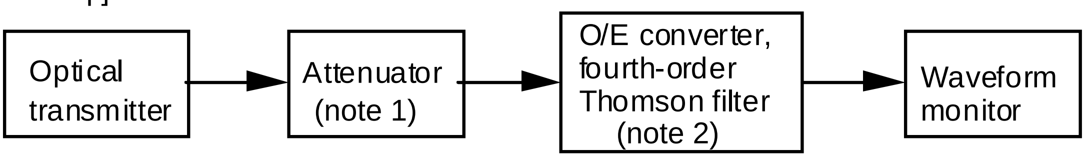
NOTE 1: Attenuator is used if necessary.

NOTE 2: Cut-off frequency (3 dB attenuation frequency) of the filter is 0,75 times output nominal bit-rate.

Figure A.6: Mask of the eye diagram for the downstream transmission signal



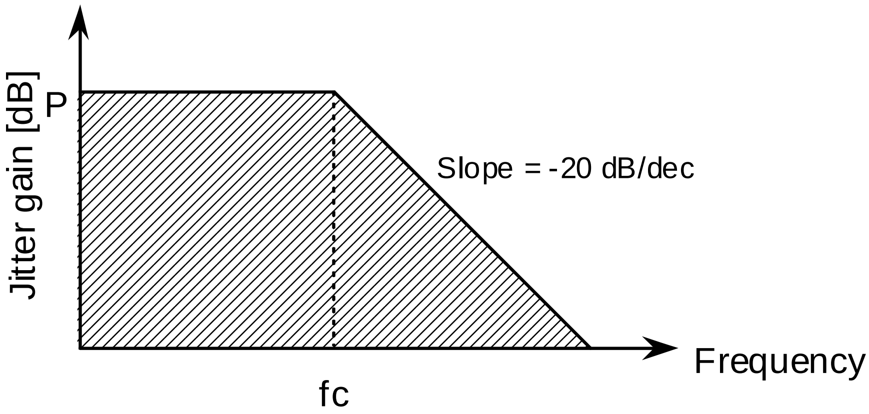
[Test set-up]



NOTE 1: Attenuator is used if necessary.

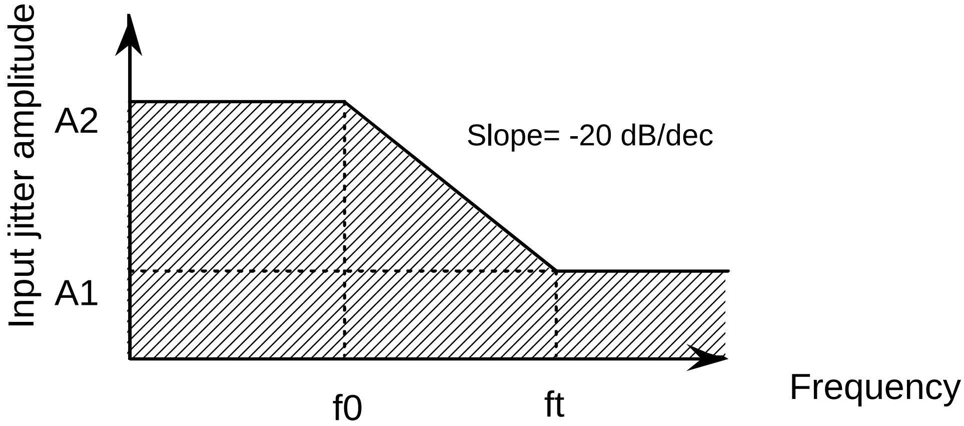
NOTE 2: Cut-off frequency (3 dB attenuation frequency) of the filter is 0,75 times output nominal bit-rate.

Figure A.7: Mask of the eye diagram for the upstream transmission signal



	fc [kHz]	P [dB]
155,52/155,52	130	0,1
155,52/622,08	500	0,1

Figure A.8: Jitter transfer for ONU



	ft [kHz]	f0 [kHz]	A1 [UIp-p]	A2 [UIp-p]
155,52/155,52	65	6,5	0,075	0,75
155,52/622,08	250	25	0,075	0,75

Figure A.9: Jitter tolerance mask for ONU

A.2.3 Transmission Convergence layer requirements for the ATM-PON

For an ATM-PON, TC layer requirements are described in table A.7.

Table A.7: TC layer requirements

Cell rate decoupling	ITU-T Recommendation I.432.1 [35]
HEC calculation error correction	ITU-T Recommendation I.432.1 [35]
Maximum number of virtual paths per PON	4 096
Minimum addressing capability	64 ONUs

NOTE: PON addressing can use the full 12 bit VP field of the ATM cell header, as is used across the VB5 reference point, see figure A.10. The VPI values on the PON do not have to equal the VPI values across the VB5 reference point, because the OLT will have a VP cross-connect function. The limit of up to 4 096 VPs avoids costly addressing tables in the ONU and enables efficient use of the PON resource.

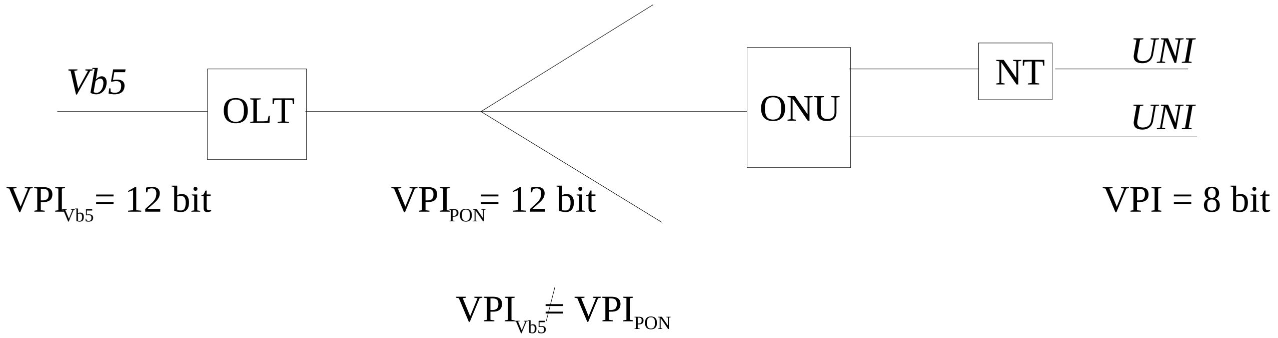


Figure A.10: VP usage on the PON

A.2.3.1 Point to multipoint transmission on the PON

The downstream signal is broadcast to all ONUs on the PON. Each upstream transmission from each ONU is controlled by OLT and is granted by the downstream by Time Division Multiple Access (TDMA) technique.

A.2.3.2 Maximum payload capacities for downstream and upstream

Minimization of overhead field in the transmission frame should be considered to maximize the payload capacity for downstream and upstream.

Required overhead capacity for the system performance and the OAM functions should be kept to meet the system requirements. However it is ideally expected that a payload capacity equivalent to a VC4 capacity could be supported in the downstream of the ATM-PON system if possible.

A.2.3.3 Downstream interface

The transfer capability for ATM cells includes information cells, signalling cells, OAM cells, unassigned cells and cells used for cell rate decoupling. The Physical Layer overhead cells include the Physical Layer OAM cells (PLOAM cells).

The transfer capacity for the 155,52 Mbit/s interface is 149,97 Mbit/s (155,52 × 54/56).

The transfer capacity for the 622,08 Mbit/s interface is 599,86 Mbit/s.

A.2.3.4 Upstream interface

The Physical Layer overhead include the PLOAM cells, the Request Access Units (RAUs) for the MAC channel and the overhead bytes which are added in front of each upstream ATM cell, PLOAM cell or RAU.

The transfer capacity for the 155,52 Mbit/s interface has an upper limit of 147,2 Mbit/s (155,52 $\times$ 53/56 Mbit/s). Some extra bandwidth is allocated by the OLT for the upstream PLOAM channel and MAC channel.

The upstream transfer capacity is shared amongst the ONUs based on their allocated upstream bandwidth.

A.2.3.5 Transport specific TC functions

A.2.3.5.1 Frame structure

The downstream interface structure for both 155,52 Mbit/s and 622,08 Mbit/s consists of a continuous stream of timeslots, each timeslot containing 53 octets of an ATM cell or a PLOAM cell.

Every 28 timeslots a PLOAM cell is inserted. A downstream frame contains 2 such PLOAM cells and is 56 slots long for the 155 Mbit/s downstream case. For the 622 Mbit/s case, it contains 8 PLOAM cells and is 224 slots long.

In the upstream direction the frame contains 53 time slots of 56 bytes. The OLT requests an ONU to transmit an ATM cell via grants conveyed in downstream PLOAM cells. At a programmable rate, the OLT requests an ONU to transmit a PLOAM cell or a minislot. The upstream PLOAM rate depends on the required functionality contained in these PLOAM cells. The minimum PLOAM rate per ONU is one PLOAM cell every 100 ms. The OLT defines the bandwidth allocated to the upstream minislots.

The PLOAM cells are used to convey the Physical layer OAM information. In addition, they carry the grants used by the ONUs for the upstream access.

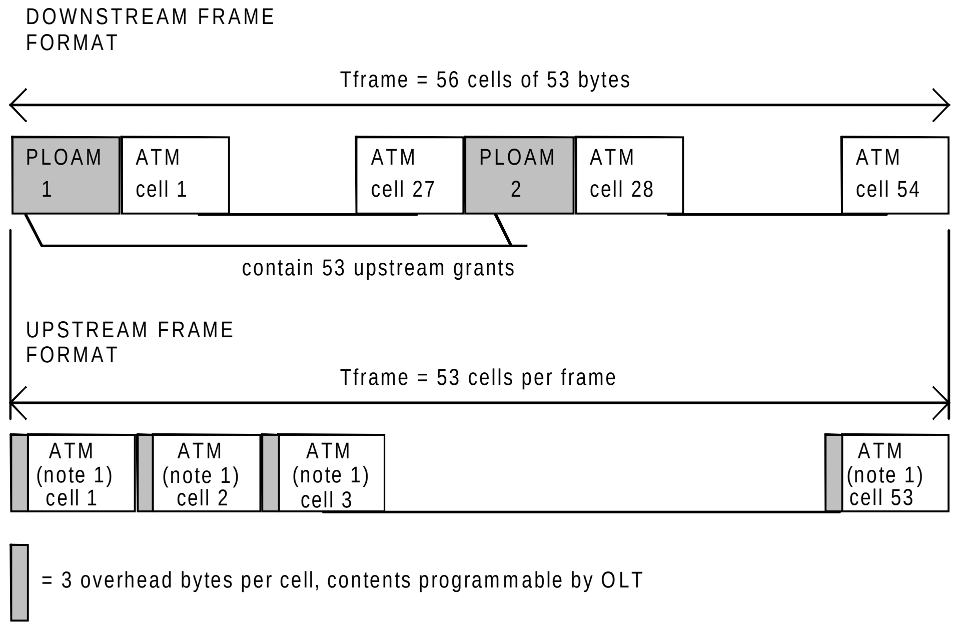
A divided_slot occupies a complete upstream time slot and contains a number of minislots from a set of ONUs. The MAC protocol uses them to transfer to the OLT the status of the ONUs queues, in order to implement a dynamic bandwidth allocation. The usage of these divided_slots is optional.

NOTE: The purpose and content of minislots are for further study.

The described frames, cells, bytes and bits are transmitted in the following order referring to their numbering: frames are transmitted in ascending order, cells within a frame are transmitted in ascending order, the bytes within a cell are transmitted in ascending order and within a byte, the most significant bit is transmitted first. The most significant bit in a byte is bit number 1 and the least significant bit is bit number 8, so for example the MSB of 0b10101010 is equal to 1.

A.2.3.5.1.1 Frame structure for symmetric PON.

The frame format for the symmetric PON is shown in figure A.11.



NOTE 1: Any ATM cell slot can contain an upstream PLOAM or divided slot, rate controlled by the OLT.

NOTE 2: ATM cells are transmitted in the order of ascending cell numbers.

Figure A.11: Frame format for 155,52/155,52 Mbit/s PON

The upstream overhead bytes are listed in table A.8.

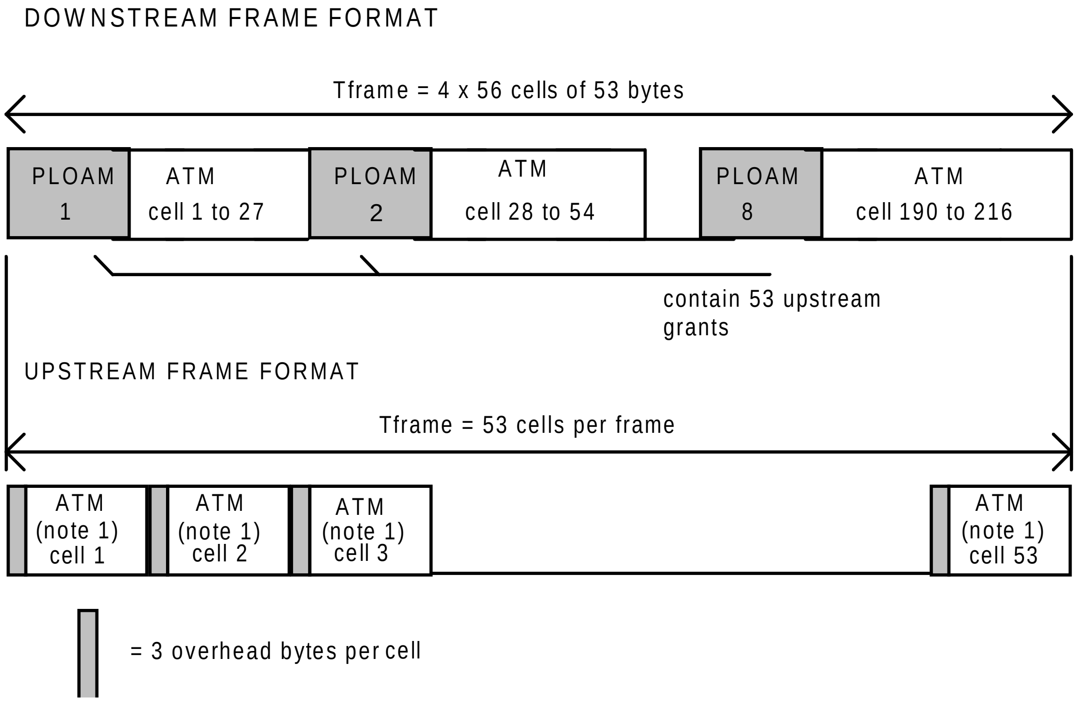
Table A.8: Upstream overhead bytes

Field	Purpose
Guard time	Provide enough distance between two consecutive cells or minislots to avoid collisions.
Preamble	Extract the phase of the arriving cell or minislot relative to the local timing of the OLT, and/or acquire bit synchronization and amplitude recovery.
Delimiter	A unique pattern indicating the start of the ATM cell or minislot, which can be used to perform byte synchronization.

The minimum guard time length is 4 bits. The total overhead length is 24 bits. The guard time length, preamble pattern and delimiter pattern are programmable under the OLT's control. The content of these fields is defined by the Upstream_overhead message in the downstream PLOAM cells.

A.2.3.5.1.2 Frame structure for 622/155 Mbit/s PON

In this case the downstream rate is exactly four times higher than for the symmetric PON, as shown in figure A.12.



NOTE 1: Any ATM cell slot can contain an upstream PLOAM or divided slot, rate controlled by the OLT.

NOTE 2: ATM cells are transmitted in the order of ascending cell numbers.

Figure A.12: Frame format for 622,08/155,52 Mbit/s PON

A.2.3.5.1.3 Time relation downstream-upstream frame.

In figures A.11 and A.12 the start of the downstream frame and the start of the upstream frame are drawn aligned to each other to indicate the equal duration of the two frames. However, the real phase difference at the reference point S/R at the OLT or ONU is undefined. Most likely, the two frames will be aligned to each other inside the OLT at some virtual reference point. The ranging process ensures that upstream cells are aligned to this upstream frame.

As described in subclause A.2.3.5.3.4 and in figures A.11 and A.12, 53 grants are mapped in the first two PLOAM cells of a frame and are numbered from 1 to 53. To guarantee a correct upstream TDMA protocol, an ONU addressed by a grant X, queues this grant (X-1) upstream cell periods before applying the equalization_delay as defined in the ranging protocol.

A.2.3.5.2 Physical layer cell identification.

ITU-T Recommendation I.432.1 [35] identifies three types of PLOAM flows carried by maintenance cells using a specific pattern in the header. The F3 flow specifies the header pattern for the transmission path level as shown in table A.9.

Table A.9: PLOAM header

	Octet 1	Octet 2	Octet 3	Octet 4	Octet 5
F3 flow	00000000	00000000	00000000	00001001	HEC=valid code 01101010
NOTE: There is no significance to any of these individual fields from the point of view of the ATM layer, as Physical Layer OAM cells are not passed to the ATM layer.					

A.2.3.5.3 Downstream PLOAM structure

Table A.10 shows the contents of the payload of the downstream PLOAM cell. The first and third column indicate the ordinal number of the payload bytes.

Table A.10: Payload content of downstream PLOAM cell

1	IDENT	25	GRANT20
2	SYNC1	26	GRANT21
3	SYNC2	27	CRC
4	GRANT1	28	GRANT22
5	GRANT2	29	GRANT23
6	GRANT3	30	GRANT24
7	GRANT4	31	GRANT25
8	GRANT5	32	GRANT26
9	GRANT6	33	GRANT27
10	GRANT7	34	CRC
11	CRC	35	MESSAGE_PON_ID
12	GRANT8	36	MESSAGE_ID
13	GRANT9	37	MESSAGE_FIELD1
14	GRANT10	38	MESSAGE_FIELD2
15	GRANT11	39	MESSAGE_FIELD3
16	GRANT12	40	MESSAGE_FIELD4
17	GRANT13	41	MESSAGE_FIELD5
18	GRANT14	42	MESSAGE_FIELD6
19	CRC	43	MESSAGE_FIELD7
20	GRANT15	44	MESSAGE_FIELD8
21	GRANT16	45	MESSAGE_FIELD9
22	GRANT17	46	MESSAGE_FIELD10
23	GRANT18	47	CRC
24	GRANT19	48	BIP

A.2.3.5.3.1 PLOAM cell termination

PLOAM cells are terminated at the Transport Specific TC layer of the ONU. The payload of the PLOAM cell is processed as long as the ONU is frame synchronized and did not detect OAML, FRML, LCD or LOS. Any cell, numbered "ATM cell 1" up to "ATM cell 54" in figure A.11 or numbered "ATM cell 1" up to "ATM cell 216" in figure A.12, that has a header equal to the specified header of a PLOAM cell, is discarded at the ONU in the ATM specific TC layer.

A.2.3.5.3.2 PLOAM Identification

Table A.11 indicates the contents of the IDENT byte.

Table A.11: Contents of IDENT field

Bits	Type	Encoding	
1..7	FU	all 0	For Future Use
8	Frame	X	It is "1" for the first PLOAM cell of a downstream frame and "0" for the others.

A.2.3.5.3.3 Frame synchronization

The ONU has to synchronize on the downstream frame based on the Frame bit in the downstream PLOAM cells before it can access the upstream link. Once the downstream ATM cell delineation is completed, the ONU synchronizes on the PLOAM rate by finding N_ploam consecutive correct PLOAM headers at a Tploam interval. Tploam is the time between two consecutive PLOAM cells. Then it synchronizes on the Frame bit by finding N_frame consecutive Frame bit=1 at a Tframe interval. This is shown in figure A.13.

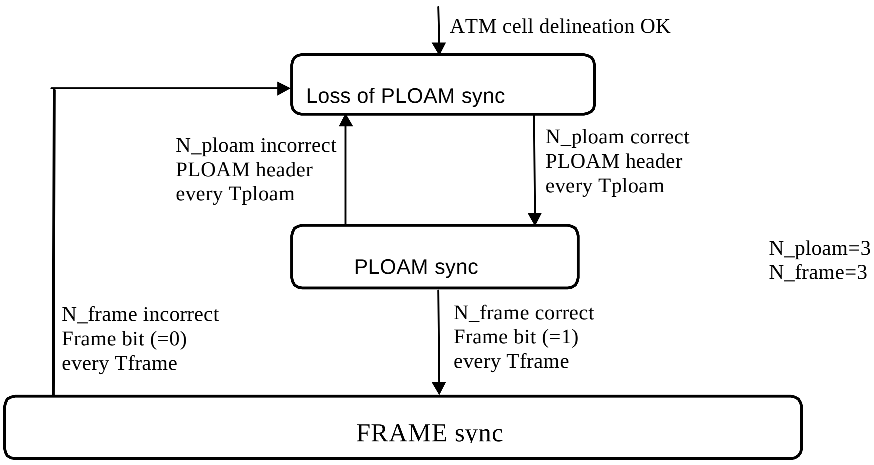


Figure A.13: Frame synchronization flow

A.2.3.5.3.4 Synchronization field (SYNC1-SYNC2)

The purpose of this field is to transport a 1 kHz reference signal provided at the OLT to the ONUs. This function is optional.

A counter in the OLT is incremented after transmission of one byte in the downstream direction for the 155 Mbit/s downstream case. For the 622 Mbit/s downstream case, this counter increments every 4 transmitted bytes. This counter is reset every 1 ms for making a 1 kHz reference signal. At the OLT, the value of that counter is taken right before transmission of the first PLOAM cell of a frame and the 15 least significant bits of the counter are placed in the 15 least significant bits of the SYNC1-SYNC2 field. The most significant bit of the counter is placed in the most significant bit of SYNC1. Depending on the length of the counter other timing references can be obtained. At reception in the ONU, this field is used to synchronize a local counter. The ONU counter is then locked on the OLT counter. This is illustrated in figure A.14.

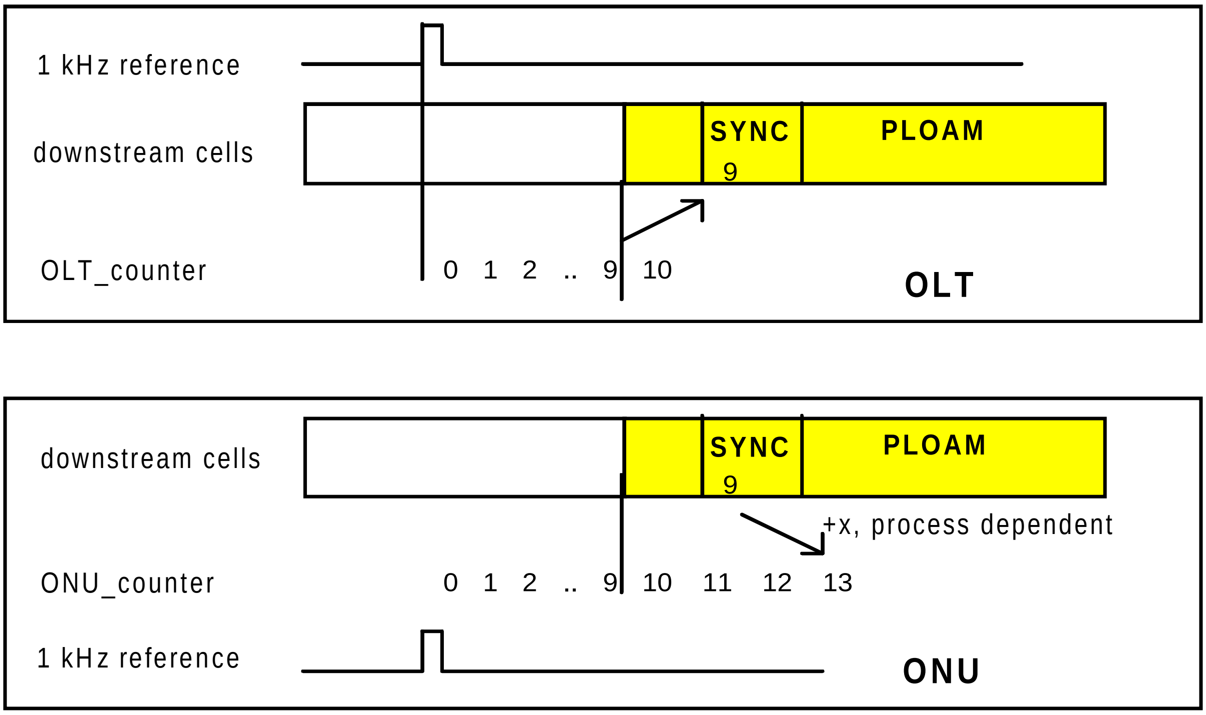


Figure A.14: 1 kHz reference extraction in ONU

A.2.3.5.3.5 Grants

Each PLOAM cell is filled with 27 grants. These grants are used by the ONUs for access on the upstream fiber. Per frame only 53 are needed. The 53 grants are mapped in the first two PLOAM cells of the downstream frame. All 53 grants are non-idle grants. The last grant of the second PLOAM cell is filled with an idle grant. The grant fields of the six remaining PLOAM cells for the asymmetrical case are all filled with idle grants and hence will not be used by the ONU. The length of a grant is 8 bit and the following types are defined in table A.12.

Table A.12: Specification of the grants

Type	Encoding	Definition
Data grant.	Any value except 11111101 11111110 11111111	For indicating an upstream ONU-specific data grant. The value of the data grant is assigned to the ONU during the ranging protocol using the grant_allocation message. The ONU can send a data cell or an idle cell if no data cell is available.
PLOAM grant	Any value except 11111101 11111110 11111111	For indicating an upstream ONU-specific PLOAM grant. The value of the PLOAM grant is assigned to the ONU during the ranging protocol using the grant_allocation message. The ONU always sends a PLOAM cell in response to this grant
Divided_slot grant	Any value except 11111101 11111110 11111111	For indicating an upstream group of ONU specific divided_slot grant. The OLT allocates the grant to a set of ONUs using the Divided_slot_grant_configuration message. Each ONU of this set sends a minislot.
Reserved grants	Any value except 11111101 11111110 11111111	In a later version of the present document other grant types will be used for specific data grants (e.g. to address a specific ONU interface or QoS class).
Ranging grant	11111101	Used for the ranging process. The condition to react to this grant is described in the ranging protocol.
Unassigned grant.	11111110	For indicating an unused upstream slot.
Idle grant.	11111111	For decoupling the downstream PLOAM rate from the upstream cell rate. These grants are ignored by the ONU

A.2.3.5.3.6 Grant protection

A CRC protects a group of 7 grants. The generating CRC polynomial for the grants is:

$$g(x) = x^8 + x^2 + x + 1$$

It can protect upto 15 bytes and has a Hamming distance of 4. It is able to detect upto 3 bit errors. No error correction is done. Once the ONU is in frame sync and as long as there is no loss of cell delineation, the grant groups are processed independent of the correctness of the PLOAM cell header.

The notation used to describe the CRC is based on the property of cyclic codes. (For example, code vectors such as 100101 can be represented by a polynomial $P(x) = x^5 + x^2 + 1$). The elements of an n-element code word are thus the coefficients of a polynomial of order n-1. In this application, these coefficients can have the value 0 or 1 and the polynomial operations are performed using modulo 2 operations. The polynomial representing the content of the group of 7 grants excluding the CRC field is generated using the first bit of this grant field as the coefficient of the highest order term.

The CRC shall be the remainder of the division (modulo 2) by the generator polynomial $x^8 + x^2 + x + 1$ of the product x^8 multiplied by the polynomial with as coefficients the content of the group of 7 grants excluding the CRC field. The most significant bit of the first grant of the group is the coefficient of the x^{55} term of this polynomial and the least significant bit of last grant of this group is the coefficient of x^0.

At the transmitter, the initial content of the register of the device computing the remainder of the division is preset to all 0 s and is then modified by division of the grant field excluding the CRC field by the generator polynomial (as described above); the resulting remainder is transmitted as the 8-bit CRC.

For the last group of 6 grants, a dummy 7th grant equal to 0b00000000 is added to calculate the CRC of this group.

When the CRC at the receiver is wrong, the entire block is ignored.

A.2.3.5.3.7 MESSAGE field

All OAM related alarms or threshold-crossing alerts triggered by events are transported via messages in the PLOAM cells. Also all ranging related messages are mapped in the message field of the PLOAM cell. The processing of a message received at the ONU relating to the ranging procedure should be completed within the time of 6 frame periods (6 × Tframe). This includes the eventual preparation of an upstream message corresponding to this downstream message. The messages are protected by the same polynomial as the grants. Once the ONU is in frame sync, the message field is processed independent of the correctness of the PLOAM cell header. No error correction is applied to this received message field. The message will be discarded at reception when the CRC is incorrect.

The CRC shall be the remainder of the division (modulo 2) by the generator polynomial $x^8 + x^2 + x + 1$ of the product x^8 multiplied by the polynomial with as coefficients the content of the message field excluding the CRC field. The most significant bit of byte 35 is the coefficient of the x^{95} term of this polynomial and the least significant bit of byte 46 is the coefficient of x^0.

At the transmitter, the initial content of the register of the device computing the remainder of the division is preset to all 0 s and is then modified by division of the message field excluding the CRC field by the generator polynomial (as described above); the resulting remainder is transmitted as the 8-bit CRC.

Table A.13 indicates the format of this message field.

Table A.13: Format of the PLOAM message

MESSAGE_PON_ID	It addresses a particular ONU. During the ranging protocol, the ONU is assigned a number, PON_ID. This PON_ID can be from 0 to 63, mapped in the range 0x00 to 0x3F. For a broadcast to all ONUs, this field is set to 0x40.
MESSAGE_ID	Indicates the type of the message.
MESSAGE_FIELD	Contains the message.

A.2.3.5.3.8 Bit Interleaved Parity (BIP8)

This field is used for monitoring the BER on the downstream link. A one byte BIP8 in each PLOAM cell covers (28 × 53)-1 bytes or 1 483 bytes between two consecutive BIPs. Each of the bits of the BIP8 byte is the XOR of all the same-position bits in all the covered bytes before scrambling. The ONU compares the received BIP8 with the BIP8 it calculated on the received byte stream. Each differing bit is counted. The BIP is a good estimate for the real BER when the BER is smaller than 10^{-4}.

A.2.3.5.4 Upstream PLOAM structure

Table A.14 shows the contents of the payload of the upstream PLOAM cell.

Table A.14: Payload content of the upstream PLOAM cell

1	IDENT	25	LCF11
2	MESSAGE_PON_ID	26	LCF12
3	MESSAGE_ID	27	LCF13
4	MESSAGE_FIELD1	28	LCF14
5	MESSAGE_FIELD2	29	LCF15
6	MESSAGE_FIELD3	30	LCF16
7	MESSAGE_FIELD4	31	LCF17
8	MESSAGE_FIELD5	32	RXCF1
9	MESSAGE_FIELD6	33	RXCF2
10	MESSAGE_FIELD7	34	RXCF3
11	MESSAGE_FIELD8	35	RXCF4
12	MESSAGE_FIELD9	36	RXCF5
13	MESSAGE_FIELD10	37	RXCF6
14	CRC	38	RXCF7
15	LCF1	39	RXCF8
16	LCF2	40	RXCF9
17	LCF3	41	RXCF10
18	LCF4	42	RXCF11
19	LCF5	43	RXCF12
20	LCF6	44	RXCF13
21	LCF7	45	RXCF14
22	LCF8	46	RXCF15
23	LCF9	47	RXCF16
24	LCF10	48	BIP

A.2.3.5.4.1 PLOAM cell termination

PLOAM cells are terminated at the Transport Specific TC layer of the OLT. The payload of the PLOAM cell is processed as long as the state of ONUi is not LOSi, LCDi, CPEi, OAMLi.

A.2.3.5.4.2 PLOAM IDENTification

Table A.15 indicates the contents of the IDENT byte.

Table A.15: Contents of IDENT field

Bits	Type	Encoding	
1..8	FU	all 0	For Future Use

A.2.3.5.4.3 MESSAGE field

All OAM related alarms or threshold-crossing alerts triggered by events are transported via messages in the PLOAM cells. Also all ranging related messages are mapped in the message field of the PLOAM cell. They are protected by the same CRC as the CRC used for the downstream message field No error correction is applied to this received message field. The message will be discarded when the CRC is incorrect or when the header of the PLOAM cell is errored.

The CRC shall be the remainder of the division (modulo 2) by the generator polynomial $x^8 + x^2 + x + 1$ of the product x^8 multiplied by the polynomial with as coefficients the content of the message field excluding the CRC field. The most significant bit of byte 2 is the coefficient of the x^{95} term of this polynomial and the least significant bit of byte 13 is the coefficient of x^0.

At the transmitter, the initial content of the register of the device computing the remainder of the division is preset to all 0 s and is then modified by division of the message field excluding the CRC field by the generator polynomial (as described above); the resulting remainder is transmitted as the 8-bit CRC.

Table A.16 indicates the format of this message field.

Table A.16: Message field format

MESSAGE_PON_ID	It contains the PON_ID of the sourcing ONU. However, the OLT knows the implicit ONU_ID since it generated a grant to it. If the contents of this field do not match the possible expected values related to this PON_ID, the message is discarded.
MESSAGE_ID	Indicates the type of the message.
MESSAGE_FIELD	Contains the message

A.2.3.5.4.4 Bit Interleaved parity (BIP8)

This field is used for monitoring the BER on the upstream link. A one byte BIP8 in each PLOAM cell is calculated by the ONU on all the bytes from the cells (though not the overhead bytes) it sent between two consecutive BIPs except the overhead bytes and minislots. Each of the bits of the BIP8 byte is the XOR of all the same position bits in all the covered bytes before scrambling. The OLT compares the received BIP8 with its own calculated BIP8. Each differing bit is counted. The coverage of the BIP8 depends on the number of cells between two consecutive PLOAMs, hence the allocated bandwidth. Since the OLT defines the PLOAM rate of a particular ONU, it can increase this rate to have a higher accuracy for the measured BER.

A.2.3.5.4.5 LCF Laser Control Field

This field is used to maintain the nominal specified mean optical output power and to control the extinction ratio when the ONU is allowed to send a cell. Since the upstream cells are scrambled, this pattern is given by the required optical transmitted pattern summed modulo 2 with the PRBS pattern of the generating polynomial of the upstream scrambler.

The ONU programs this field since it depends on the specific implementation of the upstream laser driver.

A.2.3.5.4.6 RXCF Receiver Control Field

This field is used in the upstream OLT receiver to recover the correct threshold level for regenerating the data from the incoming analog signal. The default pattern is an all ones pattern. The OLT programs this pattern using the Upstream_Rx_control message. Since the upstream cells are scrambled, this pattern is given by the required optical transmitted pattern summed modulo 2 with the PRBS pattern of the generating polynomial.

A.2.3.5.5 Divided slots

An upstream slot can contain a Divided_Slot. It fits in one upstream slot and contains a number of minislots coming from a set of ONUs. The OLT assigns one divided_slot grant to this set of ONUs for sending their minislot. The format of the divided_slot is shown in figure A.15.

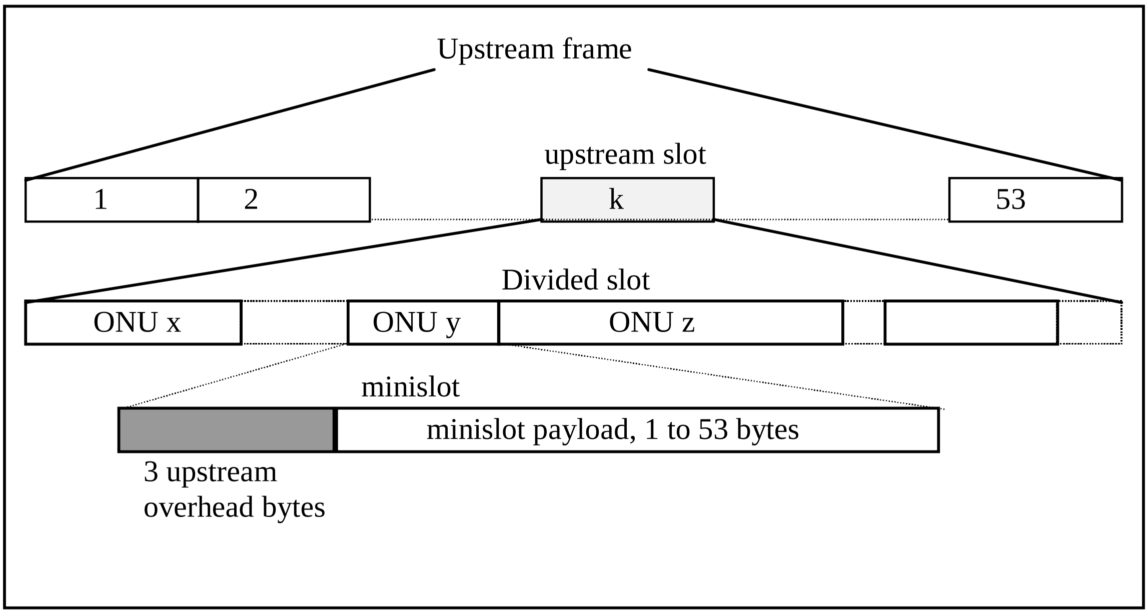


Figure A.15: Format of divided slot

The start of a minislot is at byte boundaries. The length of the minislot is a multiple number of bytes. The end of the last minislot shall be before or coincident with the end of the upstream slot. The three overhead bytes have the same definition as stated in table A.8.

A.2.3.5.6 Churning

Due to the multicast nature of the PON, downstream cells are churned with a churning key sent upstream by the ONU. The churning is performed for point to point downstream connections and churning can be only be enabled or disabled per VP at its setup. The churning key update rate is at least 1 second per ONU.

A.2.3.5.6.1 Generation of the churn key

The churn function uses a 3 byte key when this method is activated. This churn key is provided by the ONU as requested by the OLT. This key is calculated by Exclusive Or of a 3 byte randomly generated number and 3 byte data extracted from upstream user data to increase security robustness. These 3 byte codes are defined as X1 ~ X8, P1 ~ P15 and P16.

A.2.3.5.6.2 Notification of a new churn key

A new churn key is notified from ONU to OLT by "New_churn_key message". 3 byte codes, X1 ~ X8, P1 ~ P15 and P16 are conveyed in the payload of this message.

A.2.3.5.6.3 Generation of K1 ~ K9 and K10 bits in ONU and OLT

K1 ~ K9 and K10 are used in churning with a churn key. They are generated based on the above 3 byte codes as follows:

K1 and K2 bits are generated by X1 ~ X8, P13 ~ P15 and P16 in ONU and OLT respectively. The generation method is as follows:

K1=(X1*P13*P14)+(X2*P13*notP14)+(X7*notP13*P14)+(X8*notP13*notP14)

K2=(X3*P15*P16)+(X4*P15*notP16)+(X5*notP15*P16)+(X6*notP15*notP16)

where the following symbols apply:

+: logical OR

*: logical AND

not: logical NOT

K3 ~ K9 and K10 bits are generated by K1, K2, P9 ~ P11 and P12 in ONU and OLT. The generation method is as follows:

K3 = (K1*P9)+(K2*notP9)

K4 = (K1*notP9)+(K2*P9)

K5 = (K1*P10)+(K2*notP10)

K6 = (K1*notP10)+(K2*P10)

K7 = (K1*P11)+(K2*notP11)

K8 = (K1*notP11)+(K2*P11)

K9 = (K1*notP12)+(K2*notP12)

K10 = (K1*P12)+(K2*P12)

A.2.3.5.6.4 Churn function in the OLT

Downstream user data is churned based on 14 bit codes in the OLT. These codes, K1, K2, P1 ~ P11 and P12 are used for churning. Figure A.16 shows an example configuration of the churn function in OLT. The headers of the ATM cells are not churned; only the payloads of the cells are churned.

A.2.3.5.6.5 Dechurn in ONU

Received user data should be dechurned based on 14 bit codes in ONU. These codes, K1, K2, P1 ~ P11 and P12 are also used for dechurning. Figure A.16 also shows an example configuration of the dechurn function in ONU.

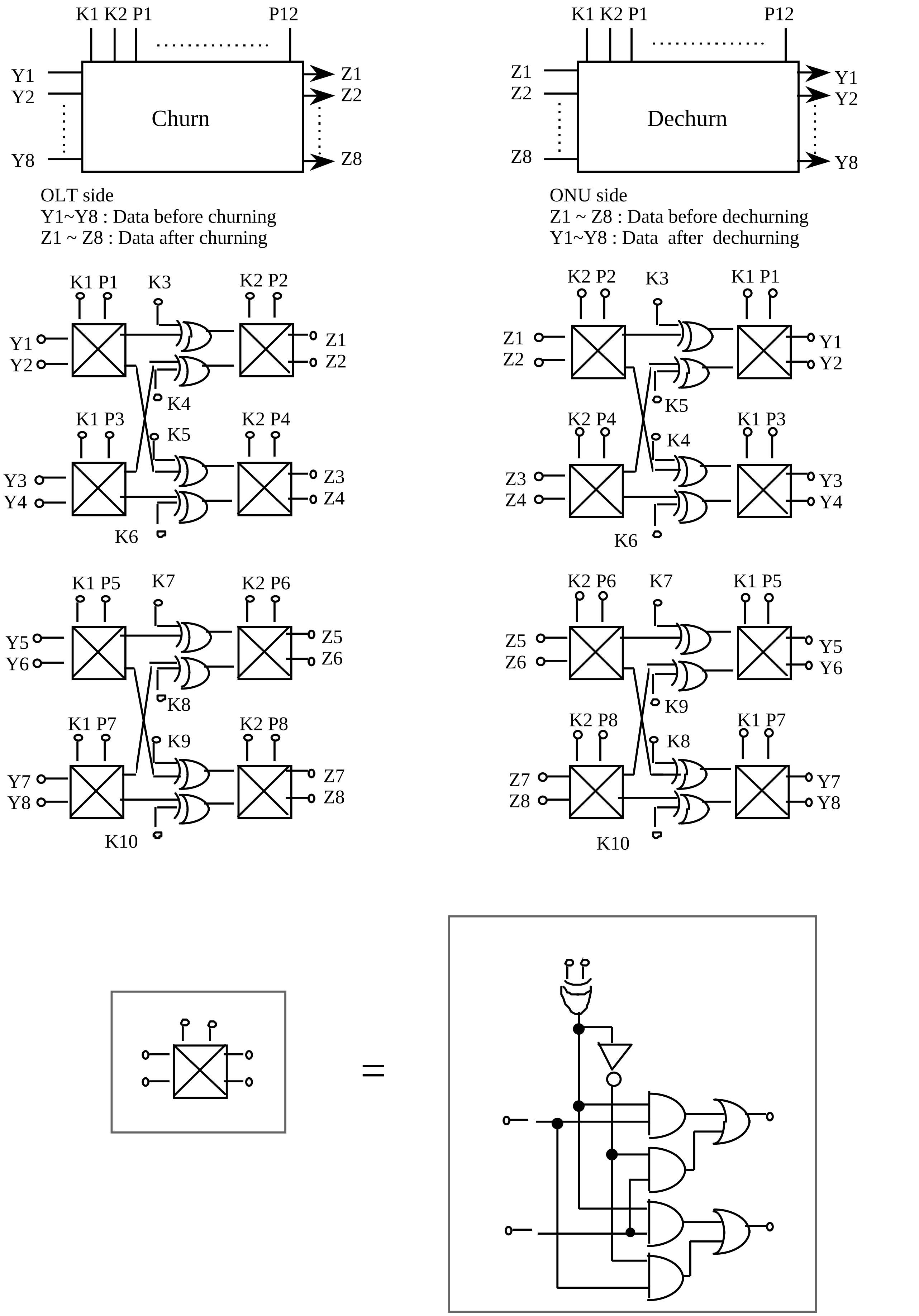


Figure A.16: Churning function

A.2.3.5.6.6 Churning message flow

The churning key is provided by the ONU on request from the OLT. Churning for an ONU starts after reception of the first key from this ONU. The churning message flow is shown in figure A.17.

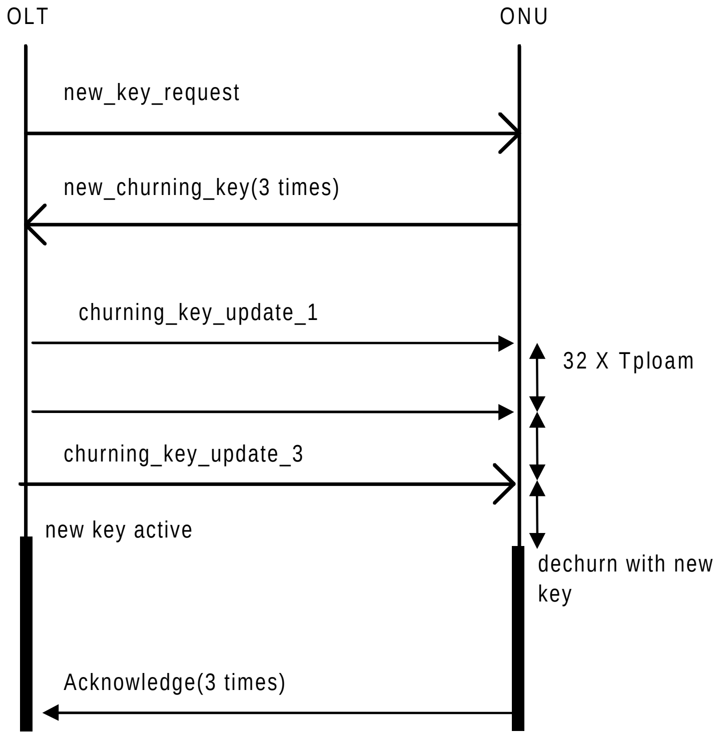


Figure A.17: Churning message flow

On receipt of the new_key_request message, the ONU responds with a new_churning_key. The ONU sends this message 3 consecutive times. If the OLT receives 3 identical new keys, it sends a churning_key_update 3 times in 3 PLOAM cells with an appropriate interval of 32 × Tploams between them to protect against loss of messages. These messages have highest priority over other possible messages. The sequence number of the message (i) is included in these messages. If at least one of these messages is received, the ONU knows when the new key is activated in the OLT since the delay between these messages is a priori known. The new key becomes valid 32 × Tploam after the third churning_key_update message. The ONU sends 3 Acknowledge messages after receiving any of the 3 churning key update messages. If the OLT receives no acknowledge after a timeout of 300 ms after sending the last churning_key_update message, the OLT detects the Loss of Acknowledge state (LOAi) for this ONU.

The OLT indicates to the ONU which VPs are churned sending the churned_VP message 3 times. It waits for an acknowledge before passing this VP downstream to the ONU. If no acknowledge is received within 300 ms after sending the last churned_VP message, the OLT detects the LOAi state.

A.2.3.5.7 Verification function

Since all the serial numbers of the ONUs can be extracted from downstream PLOAM cells as they are conveyed during the ranging protocol, a malicious user can masquerade another ONU by eavesdropping the PLOAM cells and extract all the serial numbers. The counteract this, the OLT may requests the password of the ONU. This password is only sent in upstream direction and cannot be recovered by other connected ONUs.

When the OLT request a password, the ONU responds by sending its password 3 times. If it receives three identical passwords, the OLT declares this password as valid.

Two methods are possible depending on the operator requirements. If the OLT has a table of the passwords of the connected ONUs, initialized on operator command, only a comparison is required of the received password with the local table of passwords. If the OLT doesn't know the passwords in advance, the first time the ONU is ranged the received password is taken as the reference for the rest of the lifecycle of the ONU.

If the OLT receives a non-registered password, it informs the operator.

A.2.3.5.8 VP/VC for higher layer

The TC layer activates/deactivates a downstream and an upstream VP/VC. The OLT and ONU use these VP/VCs for communication at the ATM layer. This channel is used for functions like the configuration of the UPC function in the ONU, filling filtering tables in an ONU, configuration of the interfaces of an ONU, etc.

The OLT sends 3 configure_VP/VC messages to an ONU and expects an acknowledge within 300 ms after sending the last configure_VP/VC message, depending on the upstream PLOAM rate. If no acknowledge is received, the OLT detects the LOAi state and deactivates the ONU.

A.2.3.5.9 Duplicated PON system

In case of a duplicated system where a redundant PON protects the active PON, protection switching will be activated using specified messages in PLOAM cells. This sequence will require that the line numbers of the OLT shall be totally the same as those of the ONU. This line identifier is assigned to a transmitter based on the interconnection scheme of OLTs with ONUs. The line identifier is sent at both OLT and ONU to check whether the received line identifier is the same as its own identifier. This is defined as the PON Section Trace (PST) message. Then each equipment can verify its continued connection to the intended transmitter. If the received line number differs from the own line number, the equipment generates an alarm, MIS (Link Mismatching) to notify an operator or a user.

The PST messages include the K1, K2 bytes like they are specified in ITU-T Recommendation G.783 [46] for performing Automatic Protection Switching.

In case of a singular system, link mismatching is optional.

A.2.3.5.10 MAC protocol

The MAC controller in the OLT allocates the upstream bandwidth on the PON among the ONUs in a fair way and needs information to perform this task. The ONU maps the required information in the minislot payload field of the minislot being part of a Divided_slot. An ONU is allowed to send this minislot after receiving a corresponding divided_slot grant. This grant is setup or released using the Divided_Slot_Grant_configuration message. The length and offset of the minislot are conveyed in the same message. The format for conveying this information and the MAC protocol is for further study.

A.2.3.6 ATM specific TC functions

A.2.3.6.1 Downstream

A.2.3.6.1.1 ATM cell format

The ATM cell is defined in ITU-T Recommendation I.361 [47].

A.2.3.6.1.2 Header error control

As defined in ITU-T Recommendation I.432.1 [35].

A.2.3.6.1.3 Cell delineation

As defined in ITU-T Recommendation I.432.1 [35].

A.2.3.6.1.4 Scrambler operation

As defined in ITU-T Recommendation I.432.1 [35] (distributed cell scrambler method for cell based transport systems).

A.2.3.6.1.5 Idle cells

Idle cells, as defined in ITU-T Recommendation I.432.1 [35], are inserted at the OLT and discarded at the ONU for cell rate decoupling.

A.2.3.6.1.6 PLOAM cells

Any cell, numbered "ATM cell 1" up to "ATM cell 54" in figure A.11 or numbered "ATM cell 1" up to "ATM cell 216" in figure A.12, that has a header equal to the specified header of a PLOAM cell, is discarded at the ONU.

A.2.3.6.2 Upstream

A.2.3.6.2.1 ATM cell format

As defined in ITU-T Recommendation I.361 [47].

A.2.3.6.2.2 Header error control

As defined in ITU-T Recommendation I.432.1 [35].

A.2.3.6.2.3 Cell delineation

Since upstream cells arrive from different ONUs with different phase, the OLT keeps *n* state diagrams for *n* active ONUs. Figure A.18 shows the state diagram of one ONU.

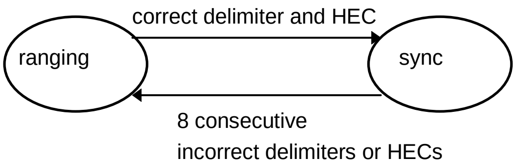


Figure A.18: Cell delineation state diagram

Initially, cell delineation is achieved by the ranging method. The ONU equalizes the round trip delay to make its cell arrive at the correct time for the OLT. The ranging process can be seen as the HUNT state as defined in ITU-T Recommendation I.432.1 [35]. After one correct delimiter and HEC, the ONU is declared in sync. For 8 consecutive incorrect delimiters or HECs, the ONU is declared out of sync (LCDi, loss of cell delineation) and it will be deactivated and reranged. Still pending grants for this ONU will be discarded.

A.2.3.6.2.4 Scrambler operation

The upstream cells are scrambled with a generating polynomial $x^9 + x^4 + 1$. It is set at all ones at reference point X shown in figure A.19. This pattern is added modulo 2 to each upstream cell or minislot. The upstream overhead bytes are not scrambled.

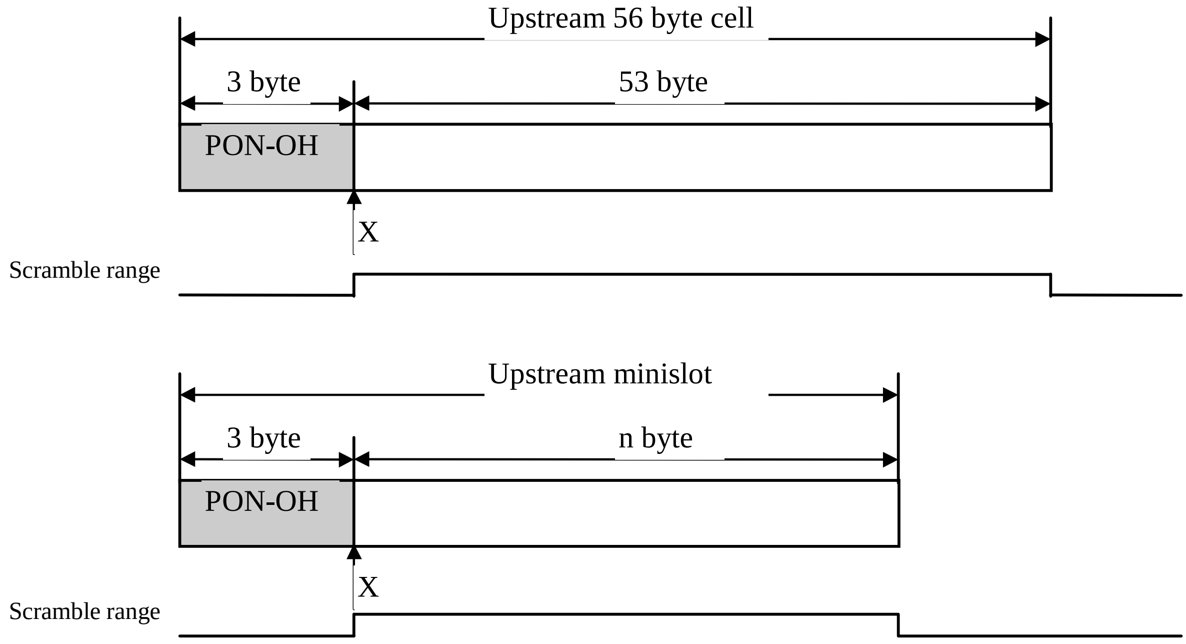


Figure A.19: Upstream scrambler

The implementation of this scrambler should be functionally equivalent to the one shown in figure A.20.

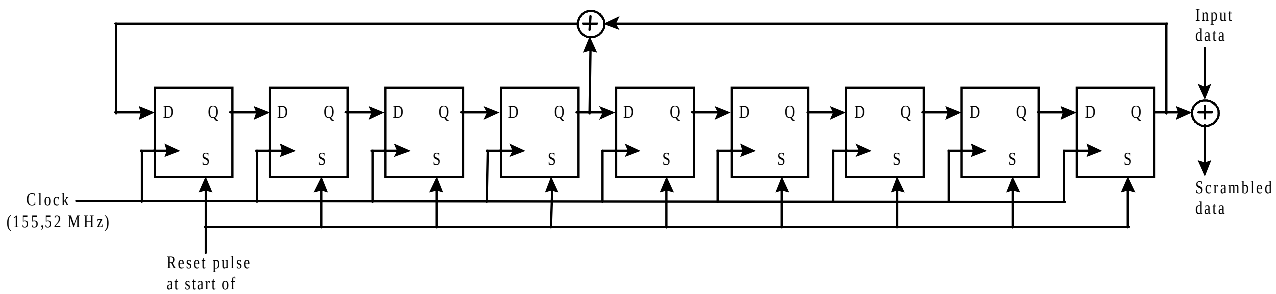


Figure A.20: Upstream scrambler

A.2.3.6.2.5 Idle cells

The ONU sends an idle cell, as defined in ITU-T Recommendation I.432.1 [35], when it receives a data grant and has no cells available. Idle cells are inserted at the ONU and discarded at the OLT for cell rate decoupling.

A.2.3.6.2.6 PLOAM cells

PLOAM cells received from the transport specific TC layer, which is an exceptional case, are discarded.

A.2.3.7 OAM functions

The OAM functions installed in the ONU and OLT are shown in figure A.17. It also shows the notification signals between OLT and ONU. These signals are mapped in the message fields of the PLOAM cells. The general principles as defined in ITU-T Recommendation I.610 [48] can be applied to the PON. However, due to the point to multipoint nature of the physical medium, some notifications from OLT to ONU are obsolete because principally the ONU slaves to the OLT and the ONU cannot do anything with these notifications.

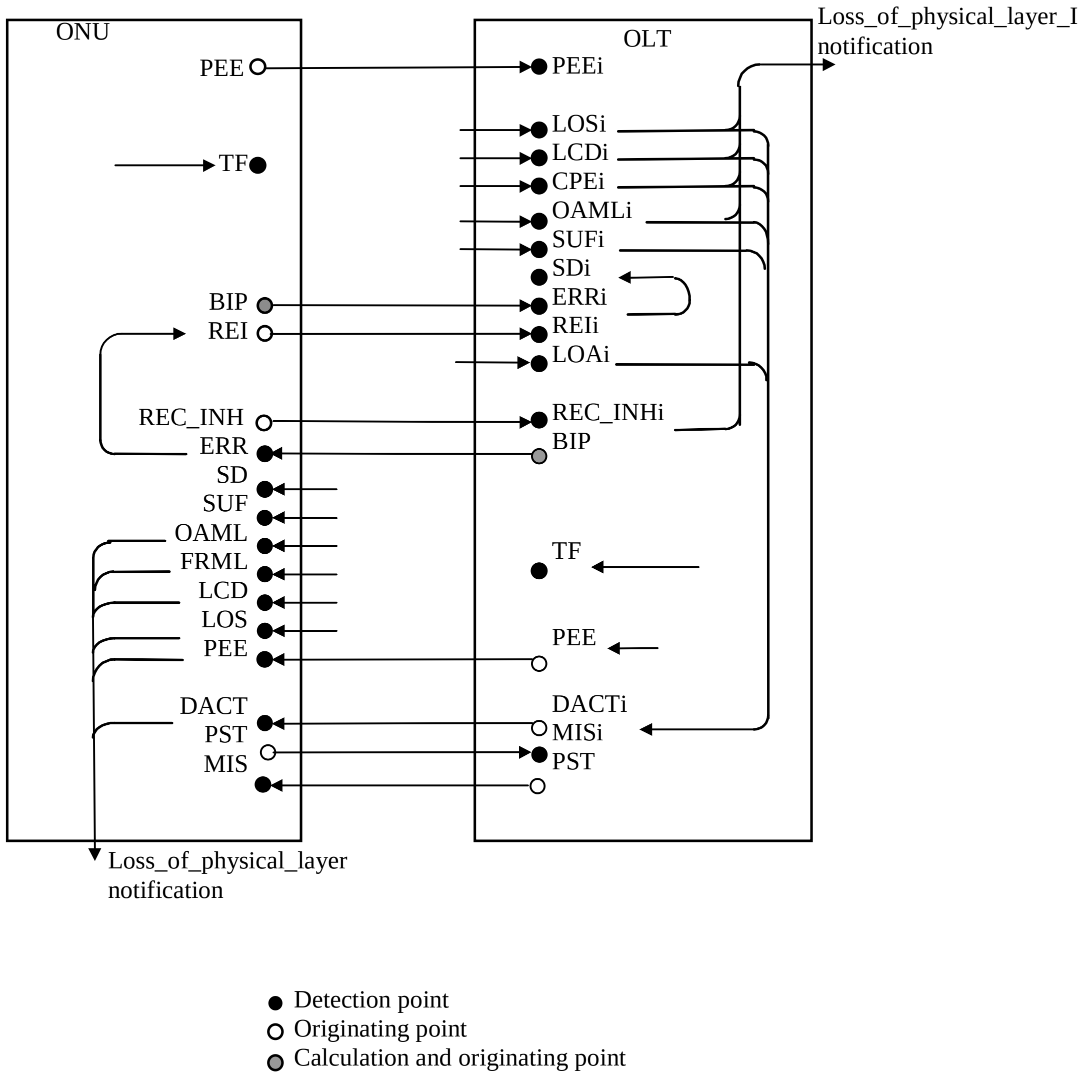


Figure A.21: OAM functions

A.2.3.7.1 Items detected at OLT

Table A.17 indicates items detected at the OLT.

Table A.17: Items detected at OLT

Type	Description	
	Detection conditions	actions
	Cancellation conditions	actions
TF	Transmitter failure	
	The OLT transmitter is declared in failure when there is no nominal backfacet photocurrent or when the drive currents go beyond the maximum specification.	
SUFi	Startup failure of ONUi	
	The ranging of ONU i has failed n times (n=2; see 8.4.4.3.3) while the OLT has received optical bursts from this ONU	Send 3 times deactivate_PON_ID messages.
	-	
PEEi	Physical Equipment Error of ONUi	
	When the OLT receives a PEE from the ONU	
	When the OLT does not receive a PEE message from the ONUi in 3 seconds.	
LCDi	Loss of cell delineation of ONUi	
	When 8 consecutive invalid delimiters or 8 consecutive invalid HECs from ONUi are received.	Send 3 times deactivate_PON_ID messages. Generate Loss_of_physical_layer_I notification.
OAMLi	PLOAM cell loss for ONUi	
	When 3 consecutive PLOAM cells of ONUi are missing	Send 3 times deactivate_PON_ID messages. Generate Loss_of_physical_layer_I notification.
CPEi	Cell phase Error for ONUi	
	When the OLT can receive the correct delimiter and the received cell phase is beyond the limits and the corrective actions of the OLT do not solve the problem.	Send 3 times deactivate_PON_ID messages. Generate Loss_of_physical_layer_I notification.
LOSi	Loss of signal of ONUi	
	No valid electrical signal at the O/E receiver received for ONUi when expected during 8 upstream sequential cells	Send 3 times deactivate_PON_ID messages. Generate Loss_of_physical_layer_I notification.
LOAi	Loss of Acknowledge with ONUi	
	The OLT does not receive an acknowledge from ONUi after a set of downstream messages that implies an upstream acknowledge.	Send 3 times deactivate_PON_ID messages.
ERRi	Block error detection of ONUi	
	The upstream received BIP8 is compared with the calculated BIP8 on the received stream. When there is a difference between them, the OLT issues ERRi.	
	ERRi should be renewed when the next upstream PLOAM cell is received at the OLT from ONUi.	

Type	Description	
SDi	Signal Degraded of ONU I	
	The number of differing bits is accumulated in Error_I during interval Tmeasure. The BER is defined as BER=Error_i/(BW × Tmeasure) where BW is the allocated upstream bandwidth. When the upstream BER of ONUi becomes > 10-5, this state is entered.	
	When the upstream BER of ONUi becomes < 10-5, this state is cleared	
REIi	Remote Error Indication of ONUi	
	When the OLT receives a REI message it issues REIi.	
	ERRi should be renewed when the REI message is received at OLT from ONUi	-
REC_INHi	Receive Alarm Inhibition of ONUi	
	When the OLT receives REC_INH message from ONUi, REC_INHi is detected	Ignore received alarms from this ONU. Generate Loss_of_physical_layer_I notification.
	-	-
MISi	Link Mismatch of ONUi	
	The OLT detects that the received PSTi and the transmitted PST are different.	
	The OLT detects that received PSTi and the transmitted PST are same.	

A.2.3.7.2 Items detected at ONU

Table A.18 indicates items detected at the ONU.

Table A.18: Items detected at the ONU

Type	Description	
	Detection conditions	actions
	Cancellation conditions	actions
TF	Transmitter failure	
	The ONU transmitter is declared in failure when there is no nominal backfacet photocurrent or when the drive currents go beyond the maximum specification	
LOS	Loss of signal	
	No valid optical signal is received at the downstream receiver. This state is entered for OAML or LCD or FRML	Switch off laser
	When the ONU reaches the cell delineation state and the PLOAM sync state and the Frame sync state.	Enable laser
PEE	Physical_Equipment_error Signal	
	When the ONU receives a PEE message	
	When the ONU does not receive a PEE message in 3 seconds.	
SUF	Startup failure	
	The ranging of this ONU has failed (see ranging protocol for exact condition)	
	When ranging is successful.	
OAML	PLOAM cell loss	
	When 3 consecutive PLOAM headers are wrong	Switch off laser
	OAM sync when 3 consecutive correct PLOAM headers	Enable laser

Type	Description	
LCD	Loss of cell delineation	
	When 7 consecutive ATM cells have an invalid HEC.	Switch off laser
	When 9 consecutive ATM cells have correct HEC.	Enable laser
FRML	Loss of downstream frame	
	When the frame bit is "0" for 3 consecutive frames	Switch off laser
	When frame bit is "1" for 3 consecutive frames.	Enable laser
ERR	Block error detection	
	The downstream received BIP8 is compared with the calculated BIP8 on the received stream. The number of differing bits is accumulated in ERR. At regular intervals, the content is sent via REI to the OLT. This interval is programmed by the OLT with a BER_interval_timer message. ERR is renewed at every reception of a downstream PLOAM cell.	REI is transmitted in the cycle of BER_interval time
	-	-
SD	Signal Degraded	
	Set active when the downstream BER exceeds 10-5	
	Set inactive when downstream BER is below 10-5	
DACT	Deactivate PON_ID	
	It instructs the ONU to deactivate itself	Stop sending upstream traffic. Switch off the laser and reset the ONU.
	Reception of Upstream_overhead message	Enable laser
MIS	Link Mismatching	
	The ONU detects that the received PST and transmitted PST are different.	
	The ONU detects that the received PST and transmitted PST are the same.	

A.2.3.8 Messages in the PLOAM channel

A.2.3.8.1 Message definition

Table A.19 defines the messages in the PLOAM channel.

Table A.19: Message definition

	Message Name	Function	Direc-tion	Trigger	Number of times sent before ONU or OLT processes it	Effect of receipt
1	No message	No message available when a PLOAM cell is transmitted	OLT → ONU	Empty message queue.	-	Discard
2	New_churning_key_rq	It requests a new churning key from the ONU.	OLT → ONU	OpS of OLT needs a new key to guarantee privacy/security requirements.	1	ONU generates a new key and conveys the key to the OLT with a new_churning_key message.
3	Upstream_RX_control	To instruct the ONU which pattern to fill in the RXCF part of the upstream PLOAM cell.	OLT → ONU	Each time a ranging process is started	3	The ONU sets the upstream RXCF field of the upstream PLOAM cell.
4	Upstream_overhead	To instruct the ONU which overhead and pre-assigned equalization delay to use in the upstream direction.	OLT → ONU	Each time a ranging process is started	3	The ONU sets the upstream overhead and the pre-assigned equalization delay.
5	Serial_number_mask	It provides a serial number and a mask masking a part of this serial number.	OLT → ONU	To find the serial number of a unique ONU.	1	If serial number and mask match the ONU's serial number, the ONU is enabled to react on ranging grants.
6	Assign_PON_ID	It links a free PON_ID number with the serial number also provided in this message.	OLT → ONU	When the OLT has found the serial number of a unique ONU.	3	The ONU with this serial number uses this PON_ID and will be addressed by this PON_ID.
7	Ranging_time	It indicates the value expressed in number of upstream bits that an ONU with PON_ID shall fill in into its equalization delay register.	OLT → ONU	When the OLT decides that the delay shall be updated, see ranging protocol.	3	The ONU fills in the equalization delay register with this value.
8	Deactivate_PON_ID	It instructs an ONU with this PON_ID to stop sending upstream traffic and reset itself. It can also be a broadcast message.	OLT → ONU	When the LOSi, LCDi, OAMLi or CPEi are detected or on command from the OpS.	3 or until no burst is detected.	The ONU with this PON_ID switches off the laser and the PON_ID is discarded. It should be activated when the MPU becomes out of order.
9	Disable_serial_ number	To disable an ONU with this serial number taking part of the contention process during the ranging protocol.	OLT → ONU	On command from the OpS..	3 or until no burst is detected.	Moves the ONU to the emergency stop state. The ONU cannot respond to grants. Upon second receipt of this message the ONU can participate in the ranging process.
10	Churning_key_update	To indicate to the ONU when the new churning key becomes valid.	OLT → ONU	When the OLT is ready to churn data for ONU with PON_ID.	3	The ONU switches to the new churning key 96 × Tploam after the first update message
11	Grant_allocation message	To allocate a data and PLOAM grant to an ONU	OLT → ONU	After a PON_ID is allocated to the ONU, it needs a data and PLOAM grant for sending the upstream data and PLOAM cells.	3	The ONU stores the two grant types.

	Message Name	Function	Direction	Trigger	Number of times sent before ONU or OLT processes it	Effect of receipt
12	Divided_Slot_Grant_ configuration message	To allocate or deallocate a Divided_slot_grant to an ONU and identify the minislot length and offset position	OLT → ONU	The OLT needs/no longer needs the service provided by the minislot	3	The ONU sends the minislot after receiving this allocated divided_slot_ grant. If deallocated, it no longer reacts to this Divided_Slot_grant.
13	Configure_VP/VC	This messages activates or deactivates a VP/VC in downstream and upstream for communication at the ATM layer	OLT → ONU	When the OLT wants to setup or tear down a connection with the ONU for example for configuration of the UPC function, filling filtering tables or configuration of the interfaces of the ONU.	3	The ONU activates/deactivates these VP/VCs for the communication channel.
14	BER_interval	It defines the accumulation interval per ONU expressed in number of downstream frames for the ONU counting the number of downstream bit errors.	OLT → ONU	OpS defines this interval and can focus on one particular ONU.	1	The ONU starts a BER_interval timer and accumulates the downstream bit errors. The sequence number in the REI messages is reset.
15	PST message	To check the OLT-ONU connectivity in a redundant configuration and to perform APS	OLT → ONU	Send it at a certain rate.	1 time / second	ONU checks link number with own link number and generates a Link Mismatch MIS if different.
16	Physical_equipment_ error message (PEE)	To indicate to the ONUs that the OLT is unable to transfer any ATM cell.	OLT → ONU	When the OLT detects it cannot transfer any ATM cells.	1 time / second	Depends on the system.
17	Churned_VP	To indicate to ONUs which VP/VC are churned or not	OLT → ONU	When a new VP shall be churned or not.	3	(Un)Mark this VP as churning and send acknowledge.
18	Request_password message	To request the password from an ONU in order to verify it. The OLT has a local table of passwords of the connected ONUs. If after a reranging, the password has changed, it will not activate this ONU.	OLT → ONU	After an ONU is ranged. This is optional	1	Send the password message 3 times.
19	POPUP message	The OLT can request all connected ONUs to restore their settings except the equalization delay and force them to go from POPUP state to Operating state O7.	OLT → ONU	To speed up the reranging of a subset or all of the connected ONUs.	3	The ONU restores the parameters it was using in operating state before it detected a LOS, LCD, OAML or FRML, except the equalization delay which is set to the pre-assigned equalization delay.
20	Vendor_specific message	A number of Message_IDs are reserved for vendor specific messages	OLT → ONU	Vendor specific	Vendor specific	Vendor specific
21	No message	No message available when a PLOAM cell is transmitted.	OLT ← ONU	Empty message queue.		Discard.
22	New_churning_key	Contains a new key to be used on the downstream churned cells to this ONU.	OLT ← ONU	After the OLT request, the ONU fetches a new key and sends it to the OLT.	3 times	The OLT initializes the churning engine with this new key if it receives 3 consecutive identical keys and switches to the new key 96Tploam after the first churning_key_update message.

	Message Name	Function	Direc-tion	Trigger	Number of times sent before ONU or OLT processes it	Effect of receipt
23	Acknowledge	It can be used by the ONU to indicate the reception of a downstream message. This is not done for all the downstream messages. This is useful for message flows where payload is affected which is not checked by the TC layer, e.g. churning process.	OLT ← ONU	After the correct reception of a downstream message, e.g. used for the churning flow.	3 times	The OLT is informed of good reception of the downstream message it was sending and performs the corresponding actions
24	Serial_number_ONU	It contains the serial number of an ONU. As an example, the Vendor_ID part of the serial number can be defined according to the basic rule described by Bellcore	OLT ← ONU	The ONU sends this message when in ranging mode and on receipt of a ranging grant or a PLOAM grant.	X (may be sent several times during the ranging protocol)	The OLT extracts the serial number and can assign a free PON_ID to this ONU.
25	Message_error message	It indicates that the ONU is unable to comply with a message from the OLT.	OLT ← ONU	When the ONU is unable to comply with a message contained in a downstream PLOAM cell.	-	Inform the operator.
26	REI (Remote Error Indication)	It contains the number of downstream bit errors counted during the BER_interval.	OLT ← ONU	When the BER_interval has expired.	1 time / BER_interval	The OLT can show the average BER in function of time for an ONU.
27	REC_INH	To inform the OLT that the ONU will power-off in a normal operation. This to prevent the OLT from issuing unnecessary alarm reports.	OLT ← ONU	The ONU generates this message when the power-off is activated in a normal operation. It should be activated when a MPU is out of order.	At least 3 times	Discard any following alarms from this ONU. Inform OpS.
28	PST message	To check the OLT-ONU connectivity in a redundant configuration and to perform APS.	OLT ← ONU	Send it at a certain rate.	1 time / second	OLT checks link number with own link number and generates a Link Mismatch MISi if different.
29	Physical_equipment_ error	To indicate to the OLT that the ONU is unable to transfer any ATM cell.	OLT ← ONU	When the ONU detects it cannot transfer any ATM cell.	1 time / second	Depends on the system.
30	Password	To verify an ONU based on its password.	OLT ← ONU	When the OLT requests the password by the "request_password" message	3	If OLT receives 3 identical passwords, it is declared as valid. Further processing is system dependant.
31	Vendor_specific message	A number of Message_Ids are reserved for vendor specific messages	OLT ← ONU	Vendor specific	-	Vendor specific

A.2.3.8.2 Message formats

This subclause defines the contents of the messages in subclause A.2.3.8.1.

A.2.3.8.2.1 Downstream message formats

Tables A.20 to A.39 define the downstream message formats.

Table A.20: No message

Octet	Content	Description
35	01000000	Broadcast message to all ONUs
36	00000000	Message identification "no message"
37..46	unspecified	

Table A.21: Upstream_Rx_control message

Octet	Content	Description
35	01000000	Broadcast message to all ONUs
36	00000001	Message identification "Upstream_Rx_control"
37	Submessage count n	n can be 0x00 or 0x01. It indicates which part of the RXCF field is indicated in the remaining octets of this message
38	dddddddd	RXCF1 for n=0x00 and RXCF10 for n=0x01
39	dddddddd	RXCF2 for n=0x00 and RXCF11 for n=0x01
40	dddddddd	RXCF3 for n=0x00 and RXCF12 for n=0x01
41	dddddddd	RXCF4 for n=0x00 and RXCF13 for n=0x01
42	dddddddd	RXCF5 for n=0x00 and RXCF14 for n=0x01
43	dddddddd	RXCF6 for n=0x00 and RXCF15 for n=0x01
44	dddddddd	RXCF7 for n=0x00 and RXCF16 for n=0x01
45	dddddddd	RXCF8 for n=0x00 and unspecified for n=0x01
46	dddddddd	RXCF9 for n=0x00 and unspecified for n=0x01

Table A.22: Upstream_overhead message

Octet	Content	Description
35	01000000	Broadcast message to all ONUs
36	00000010	Message identification "Upstream_overhead"
37	gggggggg	Number of guard bits of the upstream overhead, count starting from the first bit of the upstream overhead bytes. The value of the first gggggggg bits of overhead data in byte 38-40 are ignored by the ONU.
38	bbbbbbbb	Data to be programmed in overhead byte 1
39	bbbbbbbb	Data to be programmed in overhead byte 2
40	bbbbbbbb	Data to be programmed in overhead byte 3
41	unspecified	
42	unspecified	
43	xxxxxxxp	Message identification "preassigned equalization delay (Te)" p="0" indicates Te=0 p="1" indicates Te is defined by 44^{th}-46^{th} octets
44	dddddddd	MSB of pre-assigned equalization delay
45	dddddddd	
46	dddddddd	LSB of pre-assigned equalization delay

Table A.23: Ranging_time message

Octet	content	Description
35	PON_ID	Directed message to one ONU
36	00000011	Message identification "Ranging_time"
37	dddddddd	MSB of delay
38	dddddddd	
39	dddddddd	LSB of delay
40..46	unspecified	

Table A.24: Serial_number_mask message

Octet	Content	Description
35	01000000	Broadcast message to all ONUs
36	00000100	Message identification "Serial_number_mask"
37	nnnnnnnn	Number of valid bits, count started from LSB of byte 45 counting upto the MSB of byte 38.
38	abcdefgh	Serial number byte 1
.	.....	
45	stuvwxyz	Serial number byte 8
46	unspecified	

Table A.25: Assign_PON_ID message

Octet	Content	Description
35	01000000	Broadcast message to all ONUs
36	00000101	Message identification "Assign_PON_ID"
37	pppppppp	PON_ID.
38	abcdefgh	Serial number byte 1
.	.....	
45	stuvwxyz	Serial number byte 8
46	unspecified	

Table A.26: Deactivate PON_ID message

Octet	Content	Description
35	PON_ID	Directed message to one ONU or all ONUs. As a broadcast to all ONUs, PON_ID=0x40.
36	00000110	Message identification "Deactivate_PON_ID"
37..46	unspecified	

Table A.27: Disable_serial_number message

Octet	Content	Description
35	01000000	Broadcast message to all ONU
36	00000111	Message identification "Disable_serial_number"
37	Enable	0xFF: The ONU with this serial number is denied upstream access. 0x0F: All ONUs which were denied upstream access, can participate in ranging process. The content of byte 38~45 are irrelevant. 0x00: The ONU with this serial number can participate in the ranging process.
38	abcdefgh	Serial number byte 1
.	.....	
45	stuvwxyz	Serial number byte 8
46	unspecified	

Table A.28: New_churning_key_request message

Octet	Content	Description
35	PON_ID	Directed message to one ONU
36	00001000	Message identification "New_churning_key"
37..46	unspecified	

Table A.29: Churning_key_update message

Octet	Content	Description
35	PON_ID	Directed message to one ONU.
36	00001001	Message identification "Churning_key_update".
37	COUNT	goes from 1 to 3.
38..46	unspecified	

Table A.30: Grant_allocation message

Octet	Content	Description
35	PON_ID	Directed message to one ONU.
36	00001010	Message identification "Grant_allocation".
37	dddddddd	data grant allocated to the ONU with this PON_ID
38	0000000a	a:1 = Activate data grant for this ONU a:0 = Deactivate data grant for this ONU
39	pppppppp	ploam grant allocated to the ONU with this PON_ID
40	0000000a	a:1 = Activate PLOAM grant for this ONU a:0 = Deactivate PLOAM grant for this ONU
41..46	unspecified	

Table A.31: Divided_Slot_Grant_configuration message

Octet	Content	Description
35	PON_ID	Directed message to one ONU.
36	00001011	Message identification "Divided_Slot_Grant_configuration"
37	0000000a	a: 1 = activate grant for this ONU. a: 0 = deactivate grant for this ONU.
38	DS_GR	Defines the grant value allocated to this ONU for sending a minislot.
39	LENGTH	Defines the length of the minislot payload in number of bytes. Within the range [0,53-OFFSET]
40	OFFSET	Defines the offset of the start of the minislot in number of bytes from the start of an upstream cell slot. OFFSET=0 means minislot starts at the first byte of the upstream slot.
41	Service_ID	Defines the service to be mapped into the minislot 00000000 is used for the MAC protocol Other values are FU.
42..46	unspecified	

Table A.32: Configure VP/VC message

Octet	Content	Description
35	PON_ID	Directed message to one ONU.
36	00001100	Message identification "Configure VP/VC".
37	000000da	d: 1 byte 38-41 define downstream VP/VC d: 0 byte 38-41 define upstream VP/VC a: 1 activates this VP/VC a: 0 deactivates this VP/VC
38	HEADER1	ATM header byte 1 (MSB)
39	HEADER2	ATM header byte 2
40	HEADER3	ATM header byte 3
41	HEADER4	ATM header byte 4 (LSB)
42	MASK1	All the bits of MASK that are set define the corresponding bits in HEADER that shall be used for termination or generation of cells at the ATM layer.
43	MASK2	
44	MASK3	
45	MASK4	
46	unspecified	

Table A.33: Physical_equipment_error message

Octet	Content	Description
35	01000000	Broadcast message to all ONUs
36	00001101	Message identification "Physical_equipment_error"
37..46	unspecified	

Table A.34: Request_Password message

Octet	Content	Description
35	PON_ID	Directed message to one ONU
36	00001110	Message identification "Request_Password"
37..46	unspecified	

Table A.35: Churned_VP message

Octet	Content	Description
35	PON_ID	Directed message to one ONU
36	00001111	Message identification "Churned_VP"
37	xxxxxxxa	a=1 Churned a=0 Not churned
38	VPI[11..4]	
39	VPI[3..0]	
40..46	unspecified	

Table A.36: POPUP message

Octet	Content	Description
35	01000000	Broadcast message to all ONUs
36	00010000	Message identification "POPUP"
37..46	unspecified	

Table A.37: Vendor_specific message

Octet	Content	Description
35	xxxxxxxx	Directed message to one ONU or broadcast
36	01111zzz	Message identification "Vendor_specific"
37..46	yyyyyyyy	Vendor specific. These messages can be used for proprietary use by different vendors and will never be standardized.

Table A.38: PST message

Octet	Content	Description
35	01000000	Broadcast message to all ONUs
36	10000000	Message identification "PST"
37	Linenumber	Can be 0 or 1.
38	Control	This is the K1 byte as specified in ITU-T Recommendation G.783 [46].
39	Control	This is the K2 byte as specified in ITU-T Recommendation G.783 [46].
40..46	Unspecified	

Table A.39: BER_interval message

Octet	Content	Description
35	PON_ID	Directed message to one ONU.
36	10000001	Message identification "BER_interval"
37	Interval1	32 bit interval, MSB
38	Interval2	
39	Interval3	
40	Interval4	32 bit interval, LSB, interval in number of frames.
41..46	unspecified	

A.2.3.8.2.2 Upstream message formats

Tables A.40 to A.50 define the upstream message formats.

Table A.40: No message

Octet	Content	Description
2	PON_ID	Indicates the ONU sourcing this message
3	00000000	Message identification "no message"
4..13	unspecified	

Table A.41: New_churning_key message

Octet	Content	Description
2	PON_ID	Indicates the ONU sourcing this message
3	00000001	Message identification "New_churning_key"
4	Churning_key1	(MSB) X1, X2, … , X8 (LSB)
5	Churning_key2	(MSB) P1, P2, …, P8
6	Churning_key3	P9, P10, … , P16 (LSB)
7..13	unspecified	

Table A.42: Acknowledge message

Octet	Content	Description
2	PON_ID	Indicates the ONU sourcing this message
3	00000010	Message identification "Acknowledge"
4	DM_ID	Message identification of downstream message.
5	DMBYTE37	Byte 37 of downstream message
6	DMBYTE38	Byte 38 of downstream message
7	DMBYTE39	Byte 39 of downstream message
8	DMBYTE40	Byte 40 of downstream message
9	DMBYTE41	Byte 41 of downstream message
10	DMBYTE42	Byte 42 of downstream message
11	DMBYTE43	Byte 43 of downstream message
12	DMBYTE44	Byte 44 of downstream message
13	DMBYTE45	Byte 45 of downstream message

Table A.43: Serial_number_ONU

Octet	Content	Description
2	01000000 PON_ID	Operating standby state 2 Operating standby state 3
3	00000011	Message identification "Serial_number_ONU"
4	00000000	Byte 5 to byte 12 form the complete serial number of the ONU.
5	VID1	Vendor_ID byte 1
6	VID2	Vendor_ID byte 2
7	VID3	Vendor_ID byte 3
8	VSSN1	Vendor specific Serial number byte 1
9	VSSN2	Vendor specific Serial number byte 2
10	VSSN3	Vendor specific Serial number byte 3
11	VSSN4	Vendor specific Serial number byte 4
12	VSSN5	Vendor specific Serial number byte 5
13	unspecified	

Table A.44: Password message

Octet	Content	Description
2	PON_ID	Indicates the ONU sourcing this message
3	00000100	Message identification "Password"
4	pppppppp	Password1
..	.....	...
13	pppppppp	Password10

Table A.45: Physical_equipment_error message

Octet	Content	Description
2	PON_ID	Indicates the ONU sourcing this message
3	00000101	Message identification "Physical_equipment_error"
4..13	unspecified	

Table A.46: Vendor_specific message

Octet	Content	Description
2	xxxxxxxx	Indicates ONU sourcing this message.
3	01111zzz	Message identification "Vendor_specific"
4..13	yyyyyyyy	Vendor specific. These messages can be used for proprietary use by different vendors and will never be standardized.

Table A.47: REI message

Octet	Content	Description
2	PON_ID	Indicates the ONU sourcing this message
3	10000000	Message identification "REI message"
4	Error_count1	32 bit error counter, MSB
5	Error_count2	32 bit error counter,
6	Error_count3	32 bit error counter,
7	Error_count4	32 bit error counter, LSB
8	0000SSSS	Sequence number. The 4 LSB bits SSSS are incremented every time this message is sent.
9..13	unspecified	

Table A.48: REC_INH message

Octet	Content	Description
2	PON_ID	Indicates the ONU sourcing this message
3	10000001	Message identification "REC_INH"
4..13	unspecified	

Table A.49: PST message

Octet	Content	Description
2	PON_ID	Indicates the ONU sourcing this message
3	10000010	Message identification "PST"
4	Linenumber	Can be 0 or 1.
5	Control	This is the K1 byte as specified in ITU-T Recommendation G.783 [46]
6	Control	This is the K2 byte as specified in ITU-T Recommendation G.783 [46]
7..13	Unspecified	

Table A.50: Message_error message

Octet	Content	Description
2	PON_ID	Indicates the ONU sourcing this message
3	10000011	Message identification "Message_error"
4	Message_id	Indicates unrecognized downstream message_id
5..13	Unspecified	

A.2.3.9 Automatic protection switching

Automatic Protection Switching (APS) at the PON TC layer may be provided as an optional function. APS use depends on the number of users and service reliability. Redundant configurations of dual ODNs or dual ONUs should be considered for business applications. Some control bits for the protection protocol are reserved in the PST message field defined in section A.2.3.8. See annex E for further details.

The time required for APS, including the ranging time for 32 ONUs, shall be considered to support POTS and/or ISDN services; existing connections should not be disconnected when APS is carried out.

A.2.4 Ranging Method

A.2.4.1 Scope of the applied ranging method

A full digital in-band based ranging method should be used by the PON system to measure the logical reach distances between each ONU and the OLT. The maximum range of the PON is at least 20 km. The transmission delay measurement for each ONU should be capable of being performed whilst the PON is in-service without disrupting service to other ONUs.

The window size for the delay measurement signal can be minimized by using some information about the position of the ONU. The network operator may provision the PON with an apriori minimum and maximum OLT - ONU distance (if not, the default is 0 km minimum and 20 km maximum). The minimum and maximum distances can be provisioned with a granularity as defined by the network operator. For ONUs which have not been previously ranged, the start and end of the ranging window is determined from these provisioned minimum and maximum distances.

The ranging protocol is specified and applicable for several types of installation methods of ONUs and several types of ranging processes, if necessary, with additional or optional functions.

A.2.4.1.1 The installation method of ONUs

There are two possible example methods to install an ONU:

Method-A: The serial number of the ONU is registered at the OLT by the OpS system.

Method-B: The serial number of the ONU is not registered at the OLT by the OpS system. It requires an automatic detection mechanism of the serial number (or soft coded unique number) of the ONU.

For either Method-A or Method-B, ranging of an ONU may be initiated in two possible ways;

1) The network operator enables the ranging process to start when it is known that a new ONU has been connected. After successful ranging (or a time-out), ranging is automatically stopped.

2) The OLT periodically and automatically initiates the ranging process, testing to see if any new ONUs have been connected. The frequency of polling is programmable such that a ranging window can be opened every millisecond or every second under instruction of the OpS system.

A.2.4.1.2 Type of ranging process

Different situations as described below are possible where the ranging process may occur. There are four categories under which the ranging process would occur.

A.2.4.1.2.1 Cold PON, cold ONU

This situation is characterized when no upstream traffic is running on the PON and the ONUs have not yet received PON-IDs from the OLT.

A.2.4.1.2.2 Warm PON, cold ONU

This situation is characterized by the addition of new ONU(s) which have not been previously ranged or by the addition of previously active ONU(s) having power restored and coming back to the PON while traffic is running on the PON.

A.2.4.1.2.3 Warm PON, warm ONU

This situation is characterized by a previously active ONU which remains powered-on and connected to an active PON but is in the POPUP state described in subclause A.2.4.4.2.1. Also, this situation includes an active ONU connected to an active PON with running traffic.

A.2.4.1.2.4 Switch over

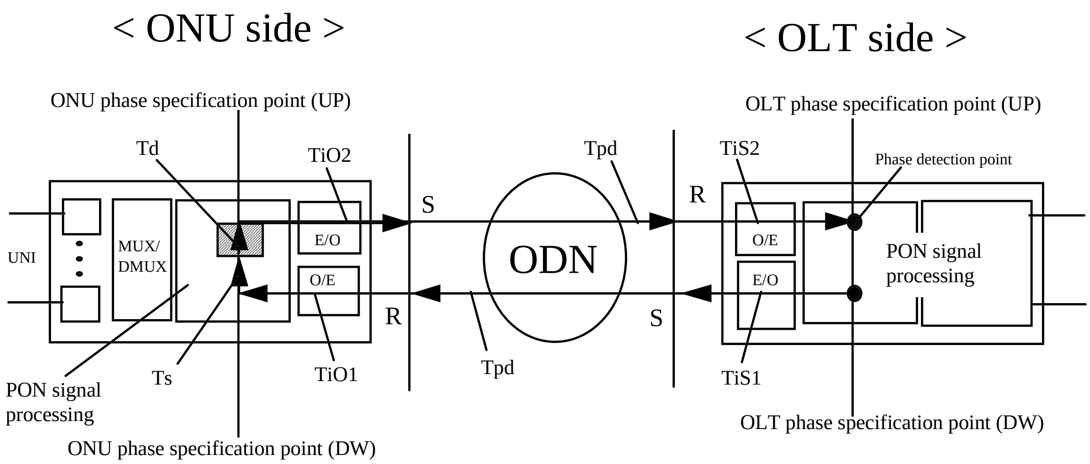
There can be several types of possible duplicated and/or partially duplicated ATM-PON configurations. The ranging protocol should be applicable in these cases.

A.2.4.2 Phase relation specification between downstream and upstream

The phase relation between downstream and upstream shall be defined for the ranging process.

A.2.4.2.1 Definition of the phase specification points

Configuration of the specification points described below is shown in figure A.22.



Tconst = TiS1 + Tpd + TiO1 + Ts + Td + TiO2 + Tpd + TiS2
Tresponse(ONU) = TiO1 + Ts + Td + TiO2 (at Td=0)
= TiO1 + Ts + TiO2
$0 \leq$ Td (Equalization_delay) $\leq$ Max

Figure A.22: Configuration of the specification points

A.2.4.2.1.1 Phase specification points of the ONU and the OLT

The ONU phase specification point is defined for the sake of convenience to specify the cell transmission phase. It is virtually located on the ONU side of the Reference point S/R. The OLT phase specification point is also defined to specify the cell transmission phase. It is virtually located on the OLT side of the Reference point R/S.

A.2.4.2.1.2 Basic cell transmission delay (Ts)

The basic cell transmission delay (Ts) is defined as the upstream cell phase, which corresponds to the first grant of the first PLOAM cell in the downstream frame, to its downstream frame at the ONU phase specification point when the equalization_delay (Td) is 0. This delay (Ts) is due to PON signal processing in the ONU.

A.2.4.2.1.3 ONU cell transmission delay

The ONU cell transmission delay is defined as the upstream cell phase, which corresponds to the first grant of the first PLOAM cell in the downstream frame, to its downstream frame at the ONU phase specification point. The ONU cell transmission delay is the sum of the basic cell transmission delay (Ts) and the equalization_delay (Td) in the ranging procedure.

A.2.4.2.1.4 Phase of interface specification points S/R and R/S

Cells in the downstream transmission at the Reference point R of the ONU reach the ONU phase specification point after a certain delay T_{iO1}. Cells in the upstream transmission at the ONU phase specification point reach the Reference point S of the ONU after T_{iO2}.

Also, cells in the downstream transmission at the OLT phase specification point reach the Reference point S of the OLT after a certain delay T_{iS1}. Cells in the upstream transmission at the Reference point R of the OLT reach the OLT phase specification point after T_{iS2}.

The delays, TiO1, TiO2, TiS1 and TiS2 are due to opto-electrical and electro-optical conversion in the ONU and OLT (as shown in figure A.22).

A.2.4.2.2 ONU response time specification

The response time in the ONU, Tresponse(ONU), at the Reference point S/R shall be specified to ensure connectivity of the furthest ONU in multi-vendor environments.

The response time Tresponse(ONU) is defined as below:

Tresponse(ONU) = TiO1 + Ts + Td + TiO2 (at Td = 0).

= TiO1 + Ts + TiO2

The value of Tresponse(ONU) shall be between 3 136 and 4 032 bits (@155,52 Mbit/s), which is equivalent to between 7 and 9 cells (with a 56 byte-cell). This is estimated as sufficient signal processing time in the ONU.

3 136 bits ≤ Tresponse(ONU) ≤ 4 032 bits (@155,52 Mbit/s)

NOTE: The delay variation due to Tresponse(ONU) is considered as an ONU location ambiguity of about the equivalent of 600 m.

A.2.4.2.3 Phase relation in the normal operation state

The relationship between the phases for the downstream and upstream cells at the Reference point S/R of the ONU, the ONU phase specification point, the Reference point R/S of the OLT, and the OLT phase specification point is shown in figure A.23. T_{pd} represents the optical fiber propagation delay from the OLT to the ONU (or vice versa).

The upstream cell time slot of cell #1 corresponds to the first grant-field of the first downstream PLOAM cell of the downstream frame. The delay between the PLOAM cell with the first grant and the corresponding upstream cell is defined as the equalized round trip delay (Teqd).

This equalized round trip delay (Teqd), is defined at the OLT phase specification point (as defined above).

$$\text{Teqd} = 2 \times \text{Tpd} + \text{Ts} + \text{Td} + T_{iO1} + T_{iO2} + T_{iS1} + T_{iS2}$$

$$= 2 \times \text{Tpd} + \text{Tresponse(ONU)} + \text{Td} + T_{iS1} + T_{iS2}$$

In the normal operating state Teqd is constant for all ONUs. Allowing for the variation of Tpd and Tresponse(ONU), the equalization_delay (Td) is specified below:

The maximum value of Td ≥ 32 000 bits (@155,52 Mbit/s).

The maximum round-trip delay of about 200 µs (equal to 20 km optical fiber) is equal to 69 cells (56 byte-cells) +192 bits and the maximum Tresponse(ONU) is 9 cells with a variation of 2 cells, so the equalization_delay should cover the delay variation from 0 to 32 000 bits (@155,52 Mbit/s).

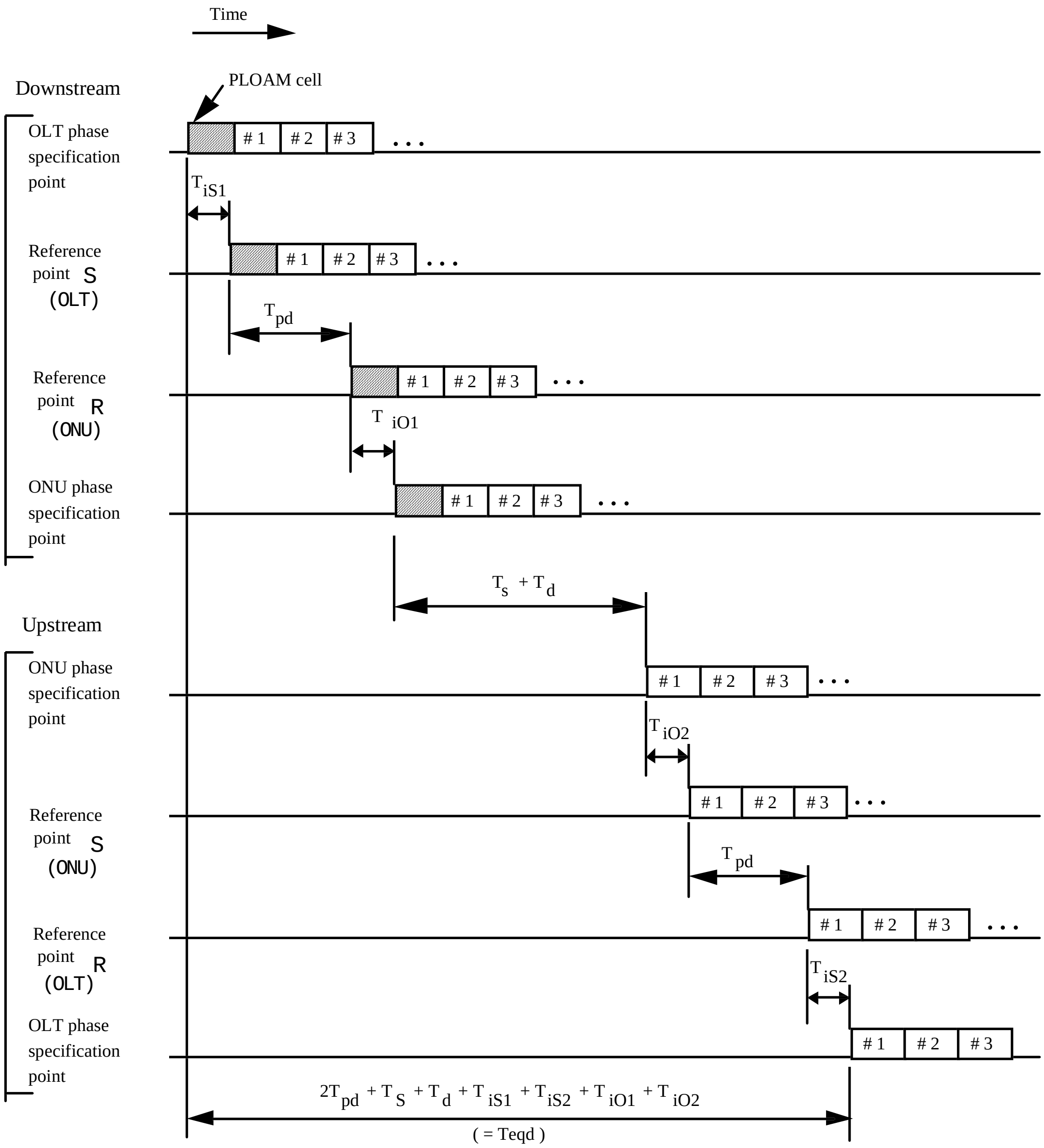


Figure A.23: Phase relationship between downstream and upstream

A.2.4.2.4 Granularity of the equalization_delay

The equalization_delay (Td) should be defined with a granularity of 1 bit @ 155,52 Mbit/s.

A.2.4.2.5 Opening the ranging window in the ranging procedure

A.2.4.2.5.1 Normal procedure

Before initiating the ranging process, the OLT sends an Upstream_overhead message to indicate to new ONUs which overhead they have to use. Then the OLT initiates the ranging process. The upstream data grants are queued.

The OLT generates a following string as:

- unassigned grants to open the window; and
- a ranging grant (or a PLOAM grant); and
- additional ranging grants or PLOAM grants if necessary.

These are mapped into the downstream PLOAM cells. This ensures that after the ranging grant leaves the OLT, an upstream window is opened to receive a ranging PLOAM cell. The additional ranging grants or PLOAM grants, allow the ONU optical power set-up and/or the OLT threshold control or amplitude finding etc. The number of additional grants for the ONU optical power set-up should be one, and those for the OLT receiver should be decided by the OLT as necessary.

When more grants are required for completion of the ONU optical power set-up, the optical power set-up can be completed by allowing several failures during ranging and repeated re-ranging. In the case that Serial number acquisition (binary tree mechanism stated in section A.2.4.4.1) is applied, the ONU may use grants for the ONU optical power set-up. Also, if the OLT periodically initiate the ranging process to check recently connected ONUs, it is useful for this purpose.

Some of the unassigned grants for the window can be replaced by data grants and/or PLOAM grants in order to minimize the window size.

This ranging window opening scheme is shown in figure A.24 for the case where the ranging grant is located in the first grant field in the first PLOAM cell of the downstream frame.

Each ONU which is permitted to send a cell(s) should send a ranging PLOAM cell(s) immediately upon receiving the ranging grant.

In this context the word "immediately" means that each ONU sends a PLOAM cell at the designated time corresponding to the ranging grant location in a downstream PLOAM cell.

The equalization_delay (Td) can be measured as in the example below for figure A.24.

Td = Teqd - (T2 - T1).

T1 = the transmission time of the downstream PLOAM cell containing a ranging grant at the OLT phase specification point.

T2 = the arrival time of the upstream ranging cell at the OLT phase specification point.

Teqd = 79 cells (as an example).

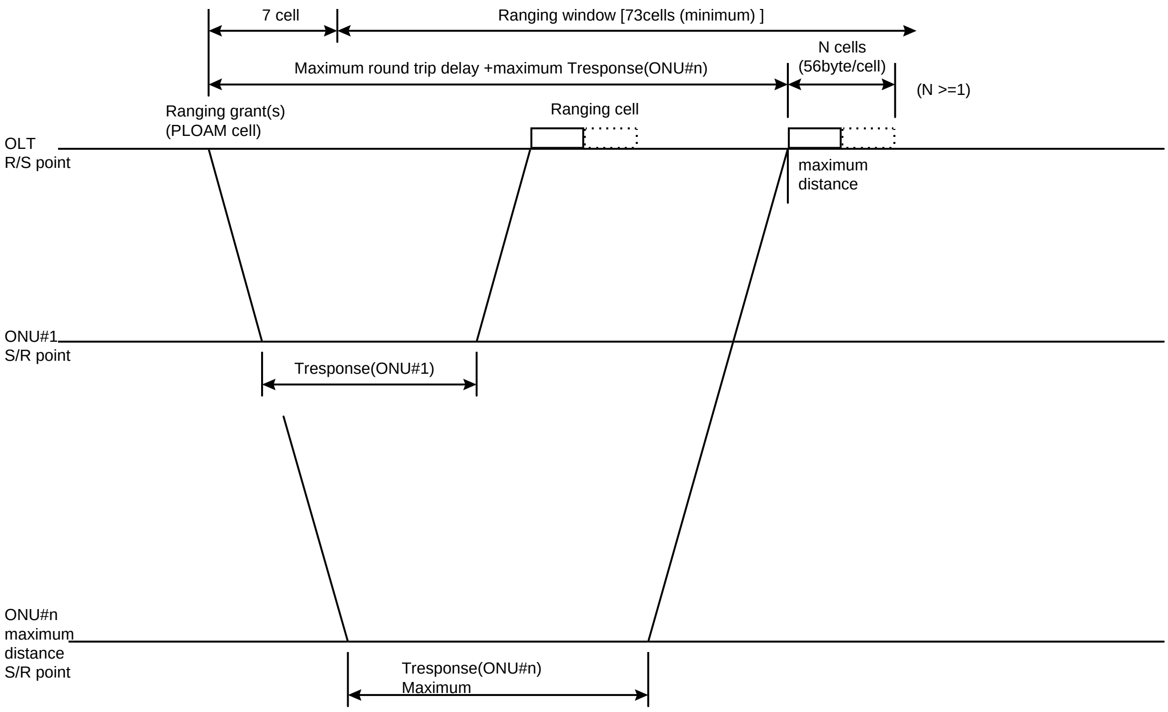
Using knowledge of the distance between the ONU and OLT, the ranging window size is programmable by assigning appropriate unassigned grants, as shown in figure A.25.

If a reduced length ranging window is requested to be opened in a fixed location in the upstream frame, then a pre-assigned equalization_delay can be used.

During the ranging process, further upstream windows can be opened as necessary. An example is shown in figure A.26.

The value "M" in this figure indicates the interval between opening windows. This value "M" should be determined from the viewpoint of avoiding a degradation in the quality of service.

The value "L" indicates the time taken to complete the ranging procedure.



If the ONU receives the ranging grant, the ONU sends a ranging cell(s) immediately.

Ranging cell is received after Tresponse(ONU) + round trip delay, in case of corresponding to the first grant of the first PLOAM cell in the downstream frame.

Ranging window size should be determined by considering additional grants.

Figure A.24: Ranging window and phase relation

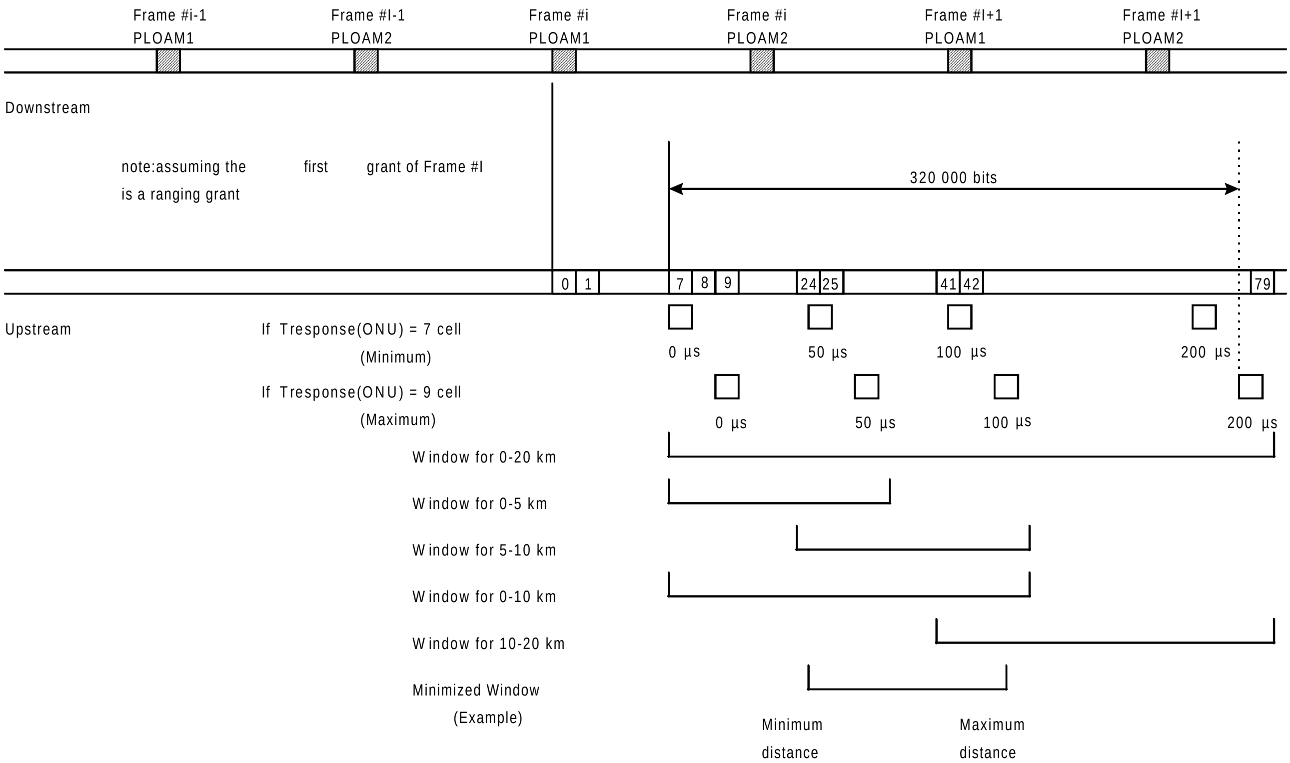


Figure A.25: Programmable ranging window (example)

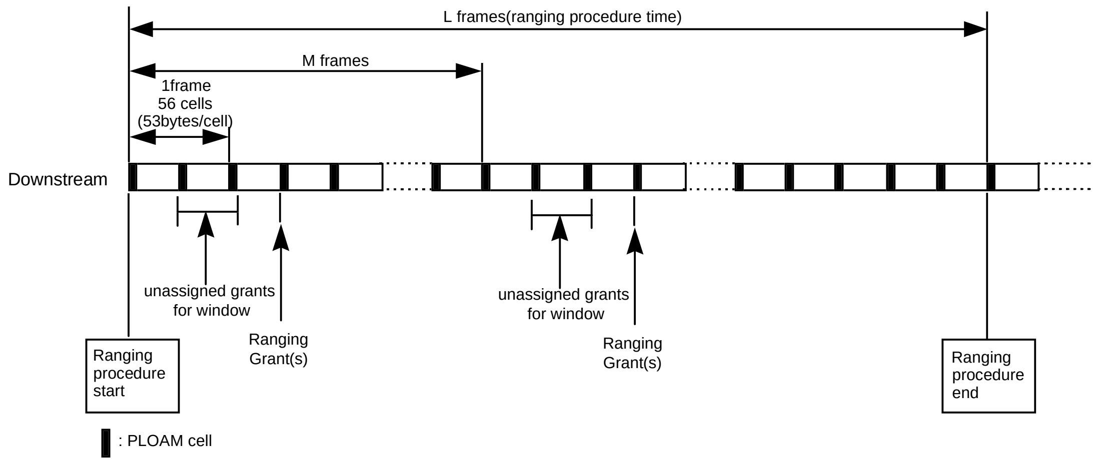


Figure A.26: Repeated opening of the ranging window

A.2.4.2.5.2 Fixed location window with some knowledge of ONU locations

Where some information about the ONU position is known, the OLT may transmit a pre-assigned equalization_delay (Te) to the ONU, where Te is equivalent to the approximate equalization_delay (Td).

The pre-assigned equalization_delay (Te) can be transmitted in the Upstream_overhead message from the OLT to each ONU. The default value of Te is equal to 0.

The OLT will transmit unassigned grants to open a ranging window, whose size is reduced from the maximum depending upon the confidence with which the OLT-ONU distance is known. It will then send a ranging grant to the ONU.

When the ONU receives the ranging grant it will respond with a ranging cell after a pre-assigned equalization_delay (Te) plus Tresponse(ONU). This will ensure that the ranging cell arrives within the opened window which is in a fixed position in the upstream frame.

An example is shown in figure A.27.

In this case, the equalization_delay (Td) can be measured as follows:

$$Td = Teqd - (T2 - T1) + Te.$$

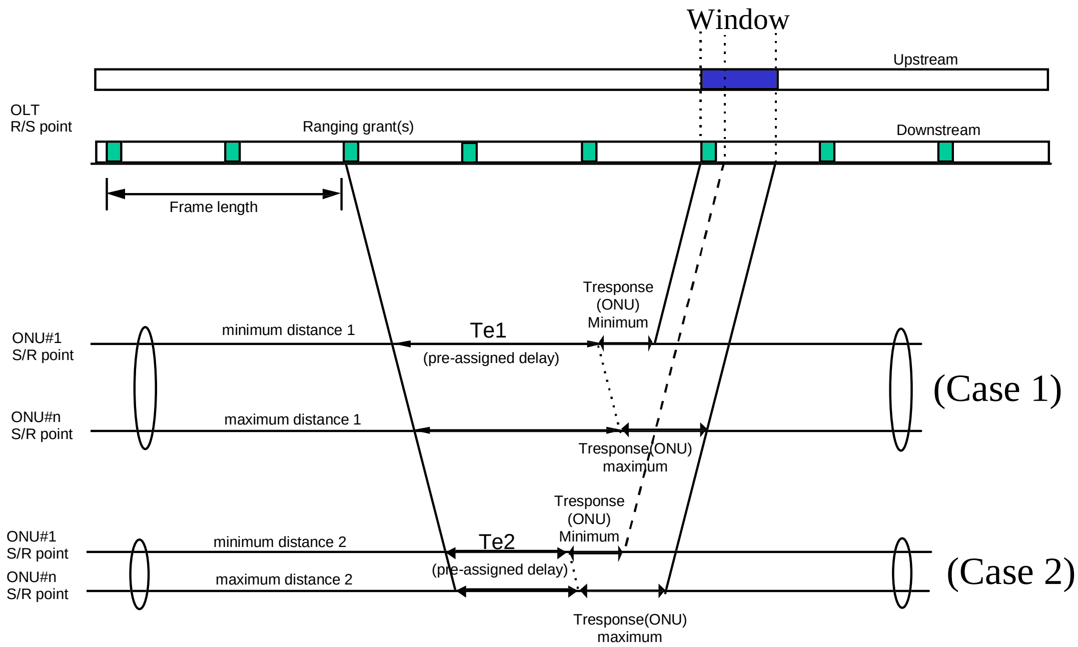


Figure A.27: Fixed location window with some knowledge about ONU locations

A.2.4.3 Definition of messages used in the ranging protocol

Messages used in the ranging protocol are defined in subclause A.2.3.

The timing relationship between downstream messages and grants in the ranging procedure should be interpreted as follows:

If a downstream PLOAM cell contains both grants and a message, the correct interpretation is defined by first acting on the grants and then on the message. The processing of messages received at the ONU relating to the ranging procedure should be completed within six frame periods (6 × Tframe). Upon receipt of the Ranging_time message, Td should also be updated within the time of 6 × Tframe. This means that the OLT should not send a PLOAM grant or a data grant to the designated ONU till 6 × Tframe seconds later after sending the first three Ranging_time messages to that ONU in ranging procedure. Because upstream cell collisions should be avoided during a message processing time in the ONU.

The timing relationship between the downstream PLOAM cells and the upstream slots is not affected by the definition described-above.

A.2.4.4 Ranging procedure

A.2.4.4.1 Overall ranging procedure

The ranging is performed under the control of the OLT. The ONU responds to messages which are initiated in the OLT.

The outline of the ranging procedure is:

- the OLT measures the arrival phase of the upstream cell from the ONU;
- the OLT notifies the ONU of the equalization_delay; and
- the ONU adjusts the transmission phase to the notified value.

This procedure is performed by the exchange of in-band digital data conveyed by upstream and downstream cells.

The ranging procedure is performed using the ranging grant, the PLOAM grant, the data grant, the ONU serial number, the PON-ID, Upstream_overhead, Upstream_Rx_control, Grant_allocation, Serial_number_mask, Assign_PON_ID and the Ranging_time messages in both the downstream PLOAM cells and the upstream PLOAM cells.

In the normal operating state, all cells can be used for monitoring the phase of the arriving cell. Based on monitoring cell phase information, the equalization_delay can be updated.

A problem with ranging may occur using installation method B when the OLT is attempting to range ONUs, and more than one ONU comes on-line at the same time. The serial number of the ONUs are not known so a ranging grant has been issued directed at all ONUs in the standby state. This can produce a response from more than one ONU, whose signals may overlap at the OLT thus causing a collision at the OLT. The Binary Tree Mechanism is used to resolve this problem:

NOTE: Binary Tree Mechanism: after a ranging cell collision has been detected at the OLT, the OLT sends a Serial_number_mask message followed by a ranging grant to allow any ONU whose serial number matches the mask to transmit a ranging cell. The size of the Serial_number_mask is increased one bit at a time until only one ONU is transmitting a ranging cell. This allows that ONU to be ranged individually. Then the general ranging grant can be re-issued allowing other ONUs still to be ranged to transmit ranging cells. If a collision still occurs then the mechanism is repeated. This Binary tree mechanism may also be useful to avoid overloading the optical input of the OLT receiver during ONU power set-up.

A.2.4.4.2 Ranging procedure in the ONU

The ranging procedure is specified by the functional behaviour in the virtually defined states and the state transition as shown below.

An example ranging flow in the ONU is described in annex D.

A.2.4.4.2.1 States of the ONU

Ten states are used for the description of the ranging behaviour:

a) Initial state (O1)

State where LOS, LCD, OAML, or FRML is still detected after the ONU has first been switched on.

b) Ranging standby state-1 (O2)

Preparation state for ranging, but the downstream message detectable state. Upstream_overhead message reception is executed. Pre-assigned equalization_delay conveyed by this Upstream_overhead message is also detected in this state.

c) Ranging standby state-2 (O3)

The ONU optical power set-up procedure is executed, if necessary. The Binary tree mechanism may be applied for ONU optical power set-up. No PLOAM cell can be transmitted in response to a ranging grant.

d) Ranging standby state-3 (O4)

The ONU optical power set-up procedure is executed, if necessary. The Binary tree mechanism may be applied for ONU optical power set-up.A PLOAM cell can be transmitted in response to a ranging grant.

e) Operating standby state-1 (O5)

PON-ID acquisition state. Binary tree mechanism is applicable for Serial number acquisition. No PLOAM cell can be transmitted in response to a ranging grant.

f) Operating standby state-2 (O6)

PON-ID acquisition state. Binary tree mechanism is applicable for Serial number acquisition. A PLOAM cell with the Serial_number_ONU message will be transmitted in response to a ranging grant.

g) Operating standby state-3 (O7)

Delay measurement executed state. A PLOAM cell with the Serial_number_ONU message will be transmitted in response to a PLOAM grant.

h) Operating state (O8)

The equalization_delay is updated by receipt of the Ranging_time message.

i) Emergency stop state (O9)

Emergency stop state after receiving Disable_serial_number message with a matching Serial_number and the enable field of FFh.

No PLOAM cell can be transmitted in response to a ranging grant.Once the ONU enters this state, the ONU should not go out this state by any of the other events listed in figure 24 such as a Deactivate_PON_ID message or LOS etc. and/or ONU power-off.

Only when the Disable_serial_number message is received with a matching Serial_number and the enable field of 00h or with the enable field of 0Fh irrespective of the Serial_number, then the state transition to O1 occurs.

j) POPUP state (O10)

The ONU enters this state after detection of LOS, LCD, OAML, or FRML in the Operating state (O8). When a POPUP message is received, the ONU restores the laser settings, Upstream_overhead, LCF and RXCF fields, Pre-equalization delay of Te, PON_ID, and Grant_allocations. A transition to O7 occurs after the timer TO1 is set to start.

A.2.4.4.2.2 Behaviour specification in the ONU

The state diagrams in tables A.51 and A.52 is used for the description of the functional behaviour in the ONU. The first column in tables A.51 and A.52 indicates the generated events including message reception, and the first row indicates the states in the ONU.

A.2.4.4.2.2.1 Message reception

The messages conveyed in the PLOAM cells from the OLT should be protected by the CRC, and the message receive event should be generated when the CRC check is correct. In the case of a), c), d), and e), these messages are sent three times to ensure correct reception at the ONU. In these cases the message receive-event is generated after the message has been received correctly at least once.

a) The receive-event of Upstream_overhead message

This event occurs in the Ranging standby state-1 only. After successful reception of the Upstream_overhead message, transition of the ONU state to Ranging standby state-2 occurs.

b) The receive-event of Serial_number_mask message

This event is processed in Ranging standby state-2, Ranging standby state-3, Operating standby state-1, and Operating standby state-2.

In Ranging standby state-2 and Ranging standby state-3:

When the valid serial number matches its own serial number, the ONU state undergoes a transition to Ranging standby state-3. If the valid serial number does not match its serial number, a transition to Ranging standby state-2 occurs.

In Operating standby state-1 and Operating standby state-2:

When the valid serial number matches its own serial number, the ONU state undergoes a transition to Operating standby state-2. If the valid serial number does not match its serial number, a transition to Operating standby state-1 occurs.

c) The receive-event of Assign_PON_ID message

This event is processed only in Operating standby state-1 and Operating standby state-2.

When the serial number in the Assign_PON_ID message matches its own serial number, PON-ID is acquired.

d) The receive-event of the Grant_allocation message

When the PON_ID in the Grant_allocation message matches its own PON-ID, a data grant and a PLOAM grant for its ONU is assigned, and then the ONU state is set to Operating standby state-3.

e) The receive-event of Ranging_time message

This event is processed only in Operating standby state-3 and Operating state when the PON_ID matches its own PON_ID.

The equalization_delay is received in the Ranging_time message and used as the equalization_delay of Td defined in the section 8.4.2.3.

In Operating standby state-3:

The equalization_delay is set, and the ONU state is set to the Operating state.

In the Operating state:

The equalization_delay is updated.

f) The receive-event of Deactivate_PON_ID message

When the PON_ID matches its own PON_ID, the ONU state undergoes a transition to Ranging standby state-1. A broadcast Deactivate_PON_ID message is also applied.

g) The receive-event of Disable_serial_number message

When the serial number (64 bits) matches its own serial number and the 37th octet of Enable in this message is equal to FFh, the ONU state undergoes a transition to Emergency stop state.

When the serial number (64 bits) matches its own serial number and the 37th octet of Enable in this message is equal to 00h, or when the Enable field is equal to 0Fh irrespective of the serial number, then the ONU state undergoes a transition to Initial state (O1) from the Emergency stop state.

h) The receive-event of POPUP message

This event occurs only in the POPUP state (O10). When a POPUP message is received, the ONU restores the laser settings, Upstream_overhead, LCF and RXCF fields, Pre-equalization delay of Te, PON_ID, and Grant_allocations. Timer TO1 is started then a transition to O7 occurs.

A.2.4.4.2.2.2 Grant reception

The data grant is processed only in the Operating state, and then an ATM cell is transmitted to the OLT. A PLOAM cell is transmitted to the OLT in response to a PLOAM grant in the Operating standby state-3 and the Operating state. The PLOAM cell transmitted in Operating standby state-3 should include the Serial_number_ONU message for confirming the ranging cell in response to the PLOAM grant.

The Ranging grant is valid only in Ranging standby state-3 and Operating standby state-2 In Ranging standby state-3, the ONU sends a PLOAM cell according to the reception of the ranging grant. This PLOAM cell may not be transmitted correctly by the ONU during laser set-up. In Operating standby state-2 the ONU sends a PLOAM cell at the designated time corresponding to the ranging grants. This PLOAM cell should be transmitted with Serial_number_ONU message for serial number acquisition by the OLT.

A.2.4.4.2.2.3 Other events

a) Optical power set-up complete

This event is generated in Ranging standby state-2 and Ranging standby state-3, only when the ONU optical power set-up has been completed. This event causes a state transition to Operating standby state-1 after timer TO1 is set to start. Sending PLOAM cells in Ranging standby state-3 are only used for ONU optical power set-up corresponding to the reception of ranging grants, if necessary. Where no optical power set-up is required then the ONU in ranging standby state-1 (O2) will extract the overhead and pre-assigned delay value from the Upstream_overhead message, move to ranging standby state-2 (O3) and then immediately generate the optical power set-up complete event and move to Operating standby state-1 (O5).

b) Timer TO1 expire

This event is generated when the delay measurement procedure is not completed within a certain time period. This event generates a state transition to Ranging standby state-2.

The value of TO1 is 10 seconds.

c) LOS, LCD, OAML, or FRML detection

This event causes the ONU state to move to the Initial state (O1) except when it is in Operating state(O8).

In Operating state(O8), this event cause the ONU state to move to the POPUP state(O10) after the timer TO2 is set to start.

d) Clear of LOS, LCD, OAML, and FRML

This event causes the ONU state to move from the Initial state to Ranging stand-by state-1.

e) Timer TO2 expire

This event is generated when the POPUP message is not received in the POPUP state within a certain time period. This event generates a state transition to Initial state (O1).

The value of TO2 is 100 milliseconds.

Table A.51: The state diagram of the ONU (1/2)

	Initial state (O1)	**Ranging standby state-1 (O2)**	**Ranging standby state-2 (O3)**	**Ranging standby state-3 (O4)**	**Operating standby state-1 (O5)**
Upstream_overhead message	-	extract overhead set pre-assigned delay Te ⇒ O3	-	-	-
Optical power set-up complete	-	-	-timer TO1 start ⇒ O5	-timer TO1 start ⇒ O5	-
Serial_number_mask message	-	-	match SN(valid bits)? ⇒ O4	unmatch SN(valid bits)? ⇒ O3	match SN(valid bits)? ⇒ O6
Assign_PON_ID message	-	-	-	-	match SN? -assign PON_ID
Grant_allocation message	-	-	-	-	match PON_ID? -allocate data/PLOAM grant ⇒ O7
POPUP message	-	-	-	-	-
timer TO2 expire	-	-	-	-	-
timer TO1 expire	-	-	-	-	⇒ O3 (alarm SUF)
Ranging_time message	-	-	-	-	-
data grant	-	-	-	-	-
PLOAM grant	-	-	-	-	-
ranging grant	-	-	-	send PLOAM cell	-
Deactivate_PON_ID message (see note)	-	-	match PON_ID? ⇒ O2	match PON_ID? ⇒ O2	match PON_ID? -timer TO1 stop ⇒ O2
Disable_serial_number message	-	-	match SN and enable = FFh? ⇒ O9	match SN and enable = FFh? ⇒ O9	match SN and enable = FFh? -timer TO1 stop ⇒ O9
detect LOS or LCD or OAML or FRML	-	⇒ O1	⇒ O1	⇒ O1	Timer TO1 stop ⇒ O1
clear LOS and LCD and OAML and FRML	⇒ O2	-	-	-	-

NOTE 1: Receive-event of a broadcast Deactivate_ PON_ID message (the 35th octet of PON_ID = 40h) is also assumed.
NOTE 2: An ONU will leave the Operating state if, a fault occurs or power is removed from the ONU. Only maintenance signals of LOS, LCD, OAML, and FRML are considered in this state diagram.
NOTE 3: "-" means no action for corresponding event.
NOTE 4: PLOAM cell in the state of O4 should be transmitted in pre-assigned delay Te.
NOTE 5: PON_ID and Grant allocation should be cleared or lost when the state transitions to O1, O2, O3, and O9 occur, and pre-assigned delay Te should be cleared in transitions to O1 and O2.

Table A.52: The state diagram of the ONU (2/2)

	Operating standby state-2 (O6)	Operating standby state-3 (O7)	Operating state (O8)	Emergency stop state-1 (O9)	POPUP state (O10)
Upstream_overhead message	-	-	-	-	-
Optical power set-up complete	-	-	-	-	-
Serial_number_mask message	unmatch SN(valid bits)? ⇒ O5	-	-		
Assign_PON_ID Message	match SN? -assign PON_ID	-	-	-	-
Grant_allocation Message	match PON_ID? -allocate data/PLOAM grant ⇒ O7	-	-	-	-
POPUP message	-	-	-	-	Restore laser settings, Upstream_overhead, LCF and RXCF fields, Te, PON_ID, and Grant allocation, timer TO1 start ⇒ O7
timer TO2 expire	-	-	-	-	⇒ O1
timer TO1 expire	⇒ O3 (alarm SUF)	⇒ O3 (alarm SUF)	-	-	-
Ranging_time message	-	match PON_ID? -timer TO1 stop -set equalization delay ⇒ O8	match PON_ID? -update equalization delay	-	-
data grant	-	-	send ATM cell	-	-
PLOAM grant	-	send PLOAM cell	send PLOAM cell	-	-
ranging grant	send PLOAM cell	-	-	-	
Deactivate_PON_ID message (see note 1)	match PON_ID? -timer TO1 stop ⇒ O2	match PON_ID? -timer TO1 stop ⇒ O2	match PON_ID? ⇒ O2		
Disable_serial_number message	match SN and enable = FFh? -timer TO1 stop ⇒ O9	match SN and enable = FFh? -timer TO1 stop ⇒ O9	match SN and enable = FFh? ⇒ O9	match SN and enable = 00h? or enable = 0Fh and SN irrelevant ⇒ O1	
detect LOS or LCD or OAML or FRML	timer TO1 stop ⇒ O1	timer TO1 stop ⇒ O1	Start timer TO2 ⇒ O10		⇒ O10
clear LOS and LCD and OAML and FRML	-	-	-	-	-

NOTE 1: Receive-event of a broadcast Deactivate_ PON_ID message (the 35th octet of PON_ID = 40h) is also assumed.

NOTE 2: An ONU will leave the Operating state if, a fault occurs or power is removed from the ONU. Only maintenance signals of LOS, LCD, OAML, and FRML are considered in this state diagram.

NOTE 3: "-" means no action for corresponding event.

NOTE 4: PLOAM cell in the state of O6, or O7 should be transmitted with its Serial_number_ONU message with pre-assigned delay Te.

NOTE 5: PON_ID and Grant allocation should be cleared or discarded when the state transitions to O1, O2, O3, and O9 occur, and pre-assigned delay Te should be cleared in transitions to O1 and O2.

A.2.4.4.3 Ranging procedure in the OLT

The ranging procedure is specified by the functional behaviour in the virtually defined states and the state transition as shown below.

An example ranging flow in the OLT is described in annex D.

A.2.4.4.3.1 States of the OLT

The OLT functions for the ranging procedure can be divided into the Common-part and the Individual-ONU-dealing-part(n), where n corresponds to each ONU. The Common-part treats a common function in one line-interface, and the Individual-ONU-dealing-part(n) treats each ONU supported in one line-interface. Each state for both parts is described below respectively with each behaviour.

A.2.4.4.3.2 Behaviour specification in the OLT

A.2.4.4.3.2.1 Common part behaviour

The state diagram used for the description of the functional behaviour in the Common-part, is shown in table A.53. The first column in table A.53 indicates the generated events and the first row indicates the states in the Common-part.

The states are defined as:

- delay measurement standby/executing state (OLT-COM1);
- serial number (SN) acquisition state (OLT-COM2).

The events are defined as follows:

a) received valid PLOAM in the window;

b) binary tree search end;

c) delay measurement condition complete (n);

This event is generated when the n-th Individual-ONU-dealing-part (n) is ready for its delay measurement.

d) not-(delay measurement condition complete (n));

e) notification of delay measurement end (n);

This event is generated for convenience when the n-th Individual-ONU-dealing-part(n) has completed its delay measurement either successfully or unsuccessfully. This event defined is useful for sequential ranging as the trigger of updating the ranged ONU number of "n", but may not be used for parallel ranging as the updating trigger. Therefore, this event is not explicitly defined in the state diagram.

f) SN acquisition request.

Table A.53: State diagram for the Common-part in the OLT

	Delay measurement standby/executing state (OLT-COM1)		**Serial number (SN) acquisition state (OLT-COM2)**
SN acquisition request	⇒OLT-COM2	-	-
Receive valid PLOAM in the window	(see note)		Extract SN allocate free n allocate free PON-ID
Binary tree search end	-		⇒OLT-COM1
NOT(Delay measurement condition complete(n))	Update n		-
Delay measurement condition complete(n)	Delay measurement start order(n)		-
NOTE: Delay measurement (Measure Td) can be performed either in the OLT Common-part or Individual-ONU-dealing-part. Therefore, this diagram does not describe this function explicitly.			

A.2.4.4.3.2.2 Individual ONU dealing part behaviour

The state diagram used for the description of the functional behaviour in the Individual-ONU-dealing-part(n), is shown in table A.54. The first column in table A.54 indicates the generated events and the first row indicates the states in the Individual-ONU-dealing-part(n).

The states are defined as:

- initial state (OLT-IDV1);

  state awaiting for the delay measurement start order

- delay measurement state (OLT-IDV2);

- operating state (OLT-IDV3).

The events are defined as follows:

a) delay measurement start order(n);

   This event is generated when instruction received from the Common-part.

b) delay measurement complete(n);

   This event is generated when the delay measurement has been performed successfully.

   After the Ranging_time message containing the equalization_delay has been sent to the designated ONU three times, Notification of delay measurement end(n) is issued for convenience to the OLT Common part, then the state transition to the Operating state(OLT-IDV3) occurs.

c) delay measurement abnormal stop(n);

   This event is generated when the delay measurement has failed.

   After the Deactivate_PON_ID message has been sent to the designated ONU three times, Notification of delay measurement end(n) is issued for convenience to the OLT Common part, then the state transition to the Initial state(OLT-IDV1) occurs.

d) detect of LOSi(n), CPEi(n), LCDi(n), OAMLi(n) or REC_INHi(n);

   This event causes the state to move to the Initial state(OLT-IDV1).

Table A.54: State diagram for the Individual-ONU-dealing-part(n) in the OLT

	Initial state (OLT-IDV1)	Delay measurement state (OLT-IDV2)	Operating state (OLT-IDV3)
Delay measurement start order(n)	⇒ OLT-IDV2	-	-
Delay measurement complete(n)	-	Send Ranging_time message 3 times. Notification of delay measurement end(n). ⇒OLT-IDV3	-
Delay measurement abnormal stop(n)	-	Send Deactivate_PON_ID message 3 times. Notification of delay measurement end(n). ⇒ OLT-IDV1	-
detect LOSi(n), CPEi(n), LCDi(n), OAMLi(n), or REC_INHi(n)	-	-	⇒ OLT-IDV1
NOTE: Notification of delay measurement end(n) is explicitly described but this event is only described for convenience. Therefore, this event should be considered as informative.			

A.2.4.4.3.3 Procedure for the equalization_delay

The equalization_delay (Td) shall be defined as described in subclause A.2.4.2.3. The specified bytes in the Ranging_time message field in the downstream PLOAM cell are set to this equalization_delay value, and this is transmitted to the ONU.

A successful equalization_delay measurement is indicated if all of the following conditions are satisfied:

1) A valid PLOAM cell is detected in the ranging window.
2) The Serial_number_ONU message in the PLOAM cell matches that of the addressed ONU.
3) The measured Td is less than or equal to a certain value (for example; 74 cells).
4) The acquisition phase of the ONU is located in less than or equal to ±2 bits, compared with the phase of the reference cell.

NOTE: The reference cell is defined as follows: the first acquisition phase has no reference cell, therefore, the equalization_delay measurement is considered as an initial success if the first received PLOAM cell satisfies all the above conditions (1)-(3). This first acquisition phase is considered as the reference phase for the next received PLOAM cell. The reference cell is updated every time the OLT receives a new valid PLOAM cell which satisfies the above conditions (1)-(3), irrespective of whether condition (4) is satisfied or not.

The delay measurement procedure consists of a series of measurements and is considered completed on having obtained two successful or two failed measurements. If performed S(=2) times this indicates a successful equalization_delay measurement and this generates the event of Delay measurement complete.

On the contrary, F(=2) times indicates failure of the equalization_delay measurement, which means that the conditions for the successful equalization_delay measurement have not been satisfied, and this generates the event of Delay measurement abnormal stop. The failure times can exclude those for threshold settings in the OLT receiver if necessary.

The calculation and transport method of the equalization_delay is as follows:

When the event of Delay measurement complete occurs, the latest successful equalization_delay value and the equalization_delay value of its reference cell are averaged and fractions of a bit are ignored. This averaged value is transmitted to the ONU as the equalization_delay.

A.2.4.4.3.4 Phase monitoring and updating equalization_delay

While the ONU is active, the phase of the received cell at the OLT is continuously checked to prevent collision with neighbouring cells. Jitter generated by the OLT clock is absorbed by the clock phase alignment method. Wander caused by temperature variation makes the upstream cell of an ONU drift towards it predecessor or successor.

The phases of the cells arriving at the OLT are averaged over a certain period with an appropriate sampling of cells for each ONU, and the updated equalization_delay is sent via the Ranging_time message to that ONU which will adjust its equalization_delay. This Ranging_ time message should be transmitted at least once within a certain maximum period.

If the OLT detects that the ONU has not adjusted its equalization_delay after a certain time-out, or if the OLT detects a cell phase error in a certain time, the OLT sends the updated equalization_delay several times. If still unsuccessful (CPEi), the OLT sends Deactivate_PON_ID message three times. If the ONU does not react to this message, the operator is informed of this anomaly. If the ONU is silenced, grant reception for this ONU is suspended. The operator is informed of this action. The operator may decide to put this ONU out of service or repeat the complete ranging procedure.

A.2.4.5 Ranging time requirements

The ranging time should be satisfied as in table A.55.

Table A.55: Ranging time

Item	PON Condition (see note 1)	ONU Condition (see note 1)	Method	Number of ONUs	Requirement
1	cold	cold	A	each ONU	2 s
2	cold	cold	B	each ONU	10 s
3	warm	cold	A	1	1 s
4	warm	cold	B	1	3 s
5	warm	cold	A/B	31	93 s
6 (see note 2)	warm	warm	A	16	100 ms
7 (see note 3)	switchover	warm	See subclause A.2.3.9		
NOTE 1: For explanation of the PON and ONU conditions see subclause A.2.4.1.2 NOTE 2: Requirement of Item 6 should be an optional but its capability should be provisioned. The capability of opening windows with programmable frequency such as every millisecond, as stated in the subclause A.2.4.1.1, could support this requirement. This may cause some traffic QOS degradation. NOTE 3: The ranging time requirements under switchover conditions are not defined here. The complete switchover process shall be completed within the time stated in subclause A.2.3.9					

A.3 Operations Administration and Maintenance (OAM) functionality

A framework has been used which consists of two axes along which the OAM functions can be classified. The first axis consists of the functional subsystem of the OAN to which the OAM function relates. The second axis is the OAM functional category.

The following functional sub-systems fulfil the OAM requirements:

1) equipment (enclosure and power);

2) transmission;

3) optical subsystem;

4) service subsystem.

OAM requirements by functional category can be defined by the five categories according to ITU-T Recommendation M.3010 [49]:

a) configuration management;

b) performance management;

c) fault management;

d) security management;

e) accounting management: out of scope.

See appendix C of ITU-T Recommendation G.982 [38] for further information.

A.4 Performance

Mean transmission delay time between T-V (or a-V) should be less than 1,5 msec as defined in ITU-T Recommendation G.982 [38]. 1,5 msec is a guideline for telephony service.

ATM cell delay variation at the ATM layer as defined by ITU-T ATM performance Recommendation I.356 [50].

A.5 Environmental recommendations

The conditions of IEC 60721-3-1 [51] are recommended.

The conditions of IEC 60801-2 [52] and 60801-3 [53] for electromagnetic compatibility are recommended.

Examples of applied environmental conditions of temperature and relative humidity for OLT and ONU are described in table A.56. The other environmental conditions such as environmental pollutants and chemicals are further study.

Table A.56: Examples of environmental conditions

Applied example	**Temperature(C)**		**Relative humidity(%)**		**Remarks**
	Normal	Short-term	Normal	Short-term	
OLT	5 to 40	-5 to 49 (see note)	5 to 85	5 to 95 (see note)	IEC721.3.3 class 3k3
Indoor ONU	-5 to 45	_	5 to 95	_	IEC721.3.3 class 3k5
Outdoor ONU	_	_	_	_	For further study
NOTE: Option 1: short term refers to a period of not more than 72 consecutive hours and a total of not more than 15 days in one year. Option 2: short term refers to a period of not more than 12 consecutive hours and a total of not more than 4 days in one year.					

A.6 Safety

A.6.1 Electrical safety and protection

The electrical safety aspects of ATM-PON equipment are for further study.

A.6.2 Optical safety and protection

The ONU transmitter optical power levels shall not exceed Class 1 as defined in IEC-825-1 (1993) [54].

NOTE: ONU optical shutdown is not required for safety reasons. An upstream link disruption caused by extraction of an optical connector or a fault condition may not lead to shutdown of the laser. ONU transmitter shutdown may however be a result from TC-layer actions.

Annex B (informative): Examples of causes of lower optical return loss in ODN

B.1 Introduction

In subclause A.2.2.7.2, the minimum ORL of the ODN at point O_{ru} and O_{rd}, and O_{ld} and O_{lu} is specified better than 32 dB. This annex describes examples of situations when the ORL can become less than 32 dB.

B.2 Effect of open connectors located at ONU side of star coupler

In the case that all ports of the star coupler are terminated, the minimum ORL in the ODN shall be better than 32 dB, but in the case that all ports of the star coupler are not terminated, the minimum ORL in the ODN shall not be better than 32 dB. As shown in figure B.1, when the optical fibre is protected between the OLT and the star coupler and one port is not terminated at the 2-branch star coupler, subject that the reflectance on the port is -13 dB and the round trip optical loss in the star coupler is -6 dB, the ORL of the ODN as viewed from the OLT is -(-13 - 6) = 19 dB.

B.3 Effect of open connectors located at OLT side of star coupler

As shown in figure B.2, when one port is not terminated at the 2-branch star coupler, subject that the reflectance of the port is -13 dB and the round trip optical loss in the star coupler is -6 dB, the ORL of the ODN as viewed from the ONU is -(-13 - 6) = 19 dB.

Especially in the case of FTTH, many connectors are allocated near the ONU. In this case, this 19 dB corresponds to a reflection of 4 PC connectors which reflectance is -25 dB for each connector.

B.4 Effect of disconnecting a connector near ONU

In figure B.3, a connector-C is disconnected with live ONU-A located near OLT and a very narrow gap appears. In this case, the optical signal from the ONU-A is reflected at the connector-C, still transmission optical signal for both upstream and downstream are not disconnected. The reflected light returns into the ONU-A and reflects again at ON-A. This "double reflected" signal may overlap a burst signal from ONU-B. Figure B.4 shows the overlap of signal.

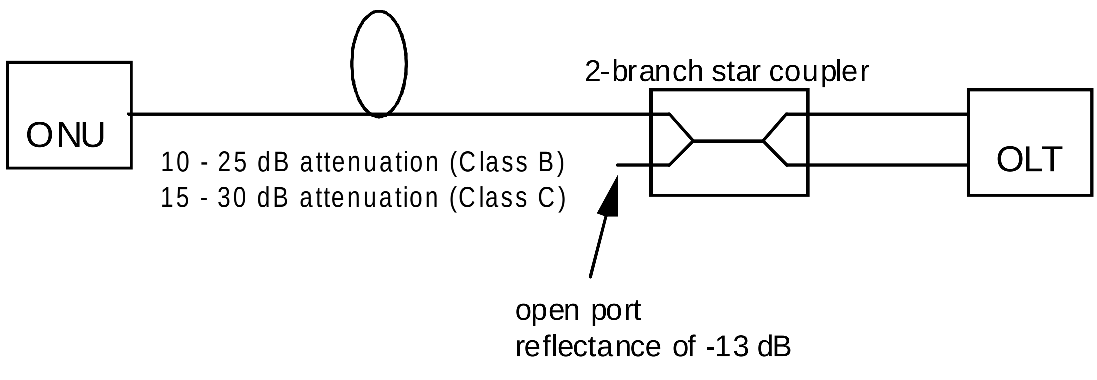


Figure B.1: Effect of open connectors located at ONU side of star coupler

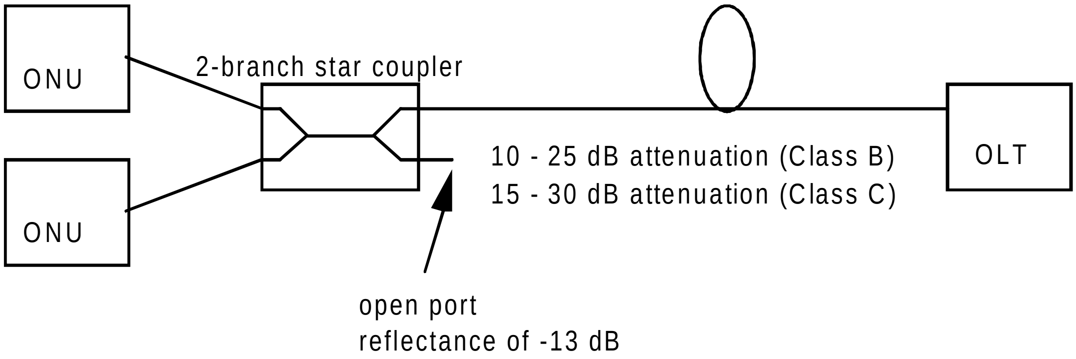


Figure B.2: Effect of open connectors located at OLT side of star coupler

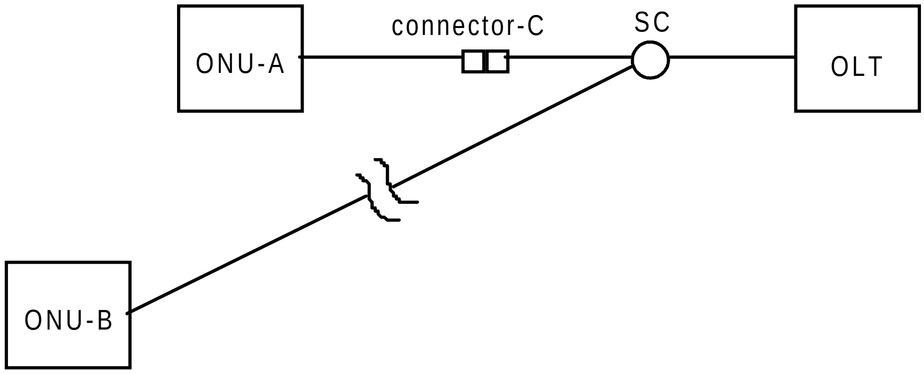
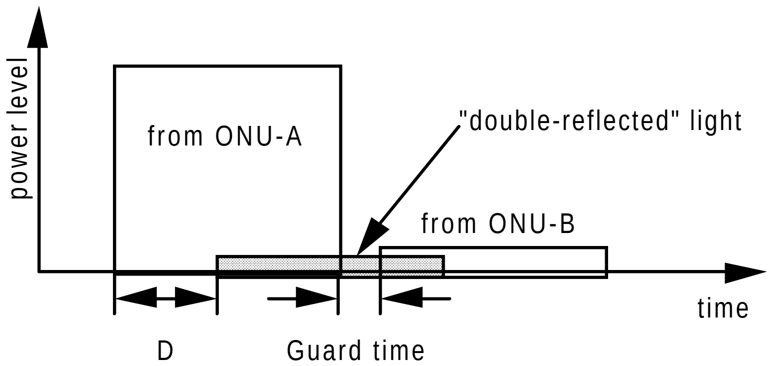


Figure B.3: Effect of disconnecting a connector near ONU



D: round trip time between ONU-A and connector-C

Figure B.4: Overlap of burst signal and reflected light

Annex C (informative): Effect of optical return loss of ODN in WDM operation

C.1 Introduction

Each network model has its own optical return loss (ORL) of ODN and PON is sensitive to the ORL of ODN. The present document describes the relationship among some types of reflectance to be considered, WDM isolation of ONU and OLT, and ONU equipment reflectance for transmitter and receiver for each case that ORL of ODN is 32 dB and 19 dB.

In the calculation of optical parameters, we assume that ONU equipment reflectance for receiver is -20 dB and OLT equipment reflectance for receiver is -20 dB. We describe condition equations and calculation results for the reflectance which restrict the parameters.

C.2 ODN optical return loss of 32 dB

C.2.1 Reflectance model to be considered

Figure C.1 illustrates the reflectance model to be considered.

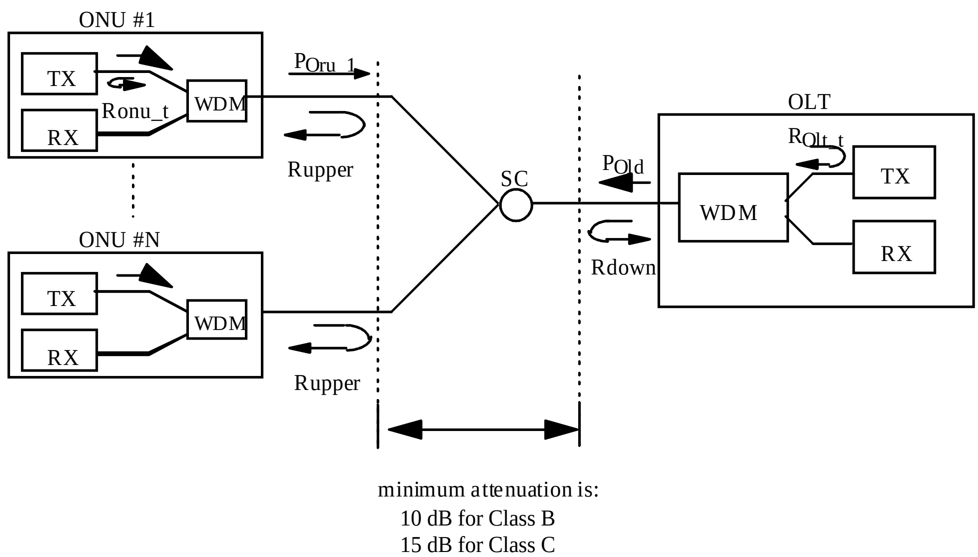


Figure C.1: Reflectance model to be considered

The following notations are used in this annex:

- P_{Oru_n}: Optical output power of ONU#n transmitter at Oru
- P_{Old}: Optical output power of OLT transmitter at Old
- Ronu_t: ONU transmitter equipment reflectance
- Rolt_t: OLT transmitter equipment reflectance
- Rupper: ORL of ODN at Oru and Ord
- Rdown: ORL of ODN at Old and Olu
- Iolt_t: WDM isolation for OLT transmitter
- Iolt_r: WDM isolation for OLT receiver
- Ionu_r: WDM isolation for ONU receiver

These values are all treated as positive in this annex.

C.2.2 Influence of reflectance into ONU receiver

Figure C.2 shows the path of reflected signal to be considered. The following equation A shall be satisfied:

P_{Oru_1} - Rupper - Ionu_r < (permissible interference optical power) **[Equation A]**

In figure C.2, transmitted signals from the other ONUs(#2 - #N) input into ONU #1. Because their transmission time is different from one of ONU#1, they are not added.

Regarding Class B, assuming permissible interference optical power is equal to (minimum sensitivity -10 dB), permissible interference optical power = -30 dBm - 10 dB = -40 dBm.

Then,

$+2 - 32 - Ionu\_r < -40.$ (1)

We obtain

$Ionu\_r > 10$ dB. (2)

Regarding Class C, assuming permissible interference optical power is equal to (minimum sensitivity -10 dB), permissible interference optical power = -33 dBm - 10 dB = -43 dBm.

Then,

$+4 - 32 - Ionu\_r < -43.$ (3)

We obtain

$Ionu\_r > 15$ dB. (4)

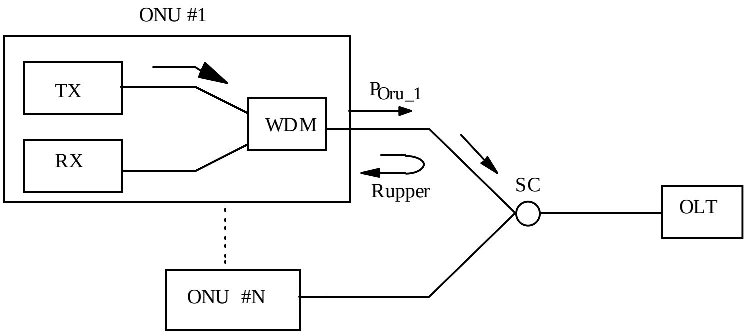


Figure C.2: Model for incidence into ONU receiver

C.2.3 Influence of reflectance into OLT receiver (in the signal region)

The analysis for the influence of reflectance into OLT receiver is performed in two conditions; one is that the reflected signal overlaps the upstream burst signal region and the other is that the reflected signal is in the delay measurement window where there is no signal.

In the signal region, the following three cases are to be considered.

C.2.3.1 Case 1

Figure C.3 shows the path of reflectance signals. The following equation B shall be satisfied:

(maximum differential of bursted signal optical levels) - Rupper - Ronu_t <
(permissible interference optical power ratio)

[Equation B]

Assuming permissible interference optical power ratio is -10 dB, we obtain

(15 + 6) - 32 - Ronu_t < -10, (5)

then

Ronu_t > -1 dB. (6)

Therefore requirement for Ronu_t in this case is not necessary.

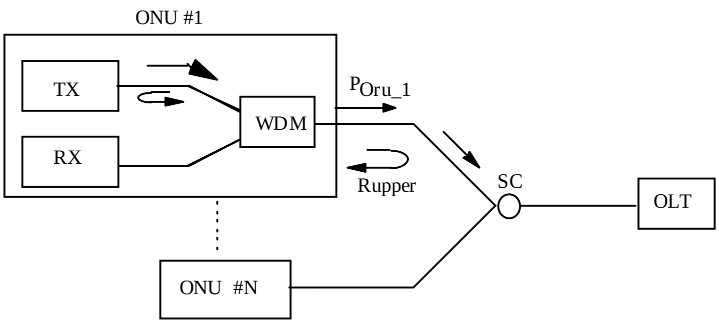


Figure C.3: Model 1 for incidence into OLT receiver

C.2.3.2 Case 2

Figure C.4 shows the path of reflectance signals. The following equation C shall be satisfied:

(maximum differential of burst signal optical level) - Rolt_t - Rdown - Iolt_t x 2 < (permissible interference optical power)

[Equation C]

Assuming permissible interference optical power is equal to -10 dB, we obtain

(15 + 6) - Rolt_t - 32 - Iolt_t x 2 < -10, (7)

then

Rolt_t + Iolt_t x 2 > -1 dB. (8)

Both of Rolt_t and Iolt_t are positive number, so requirement for Rolt_t and Iolt_t in this case is not necessary.

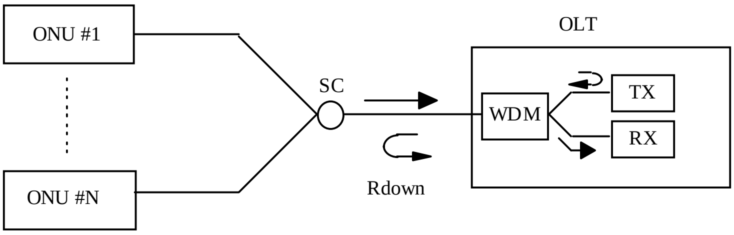


Figure C.4: Model 2 incidence into OLT receiver

C.2.3.3 Case 3

Figure C.5 shows the path of reflectance signals. The following equation D shall be satisfied:

P_{Old} - Rdown - Iolt_r < (permissible interference optical power) **[Equation D]**

Regarding Class B, assuming permissible interference optical power is equal to minimum sensitivity -10 dB, permissible interference optical power = -30 dBm - 10 dB = -40 dBm.

Then,

+2 -32 - Iolt_r < -40. (9)

We obtain,

Iolt_r > 10 dB (10)

Regarding Class C, assuming permissible interference optical power is equal to minimum sensitivity -10 dB, permissible interference optical power = -33 dBm - 10 dB = -43 dBm.

Then,

+4 -32 - Iolt_r < -43. (11)

We obtain,

Iolt_r > 15 dB (12)

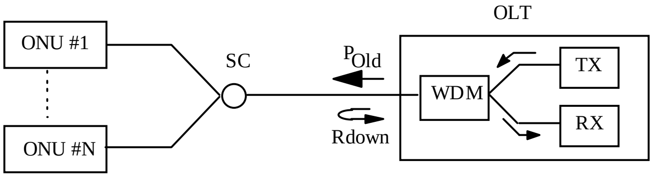


Figure C.5: Model 3 for incidence into OLT receiver

C.2.4 Influence of reflectance into OLT receiver (in the no signal region)

In the no signal region, the main cases of reflectance to be considered are the following two cases.

C.2.4.1 Case 1

Figure C.3 shows the path of reflectance signals. The following equation E shall be satisfied:

P_{Oru_1} - Rupper - Ronu_t - (minimum optical path attenuation) < (determination level as no signal)

[Equation E]

Regarding Class B, assuming determination level as no signal is equal to minimum sensitivity -10 dB, determination level as no signal = -30 dBm - 10 dB = -40 dBm.

Then,

+2 -32 - Ronu_t -10 < -40. (13)

We obtain,

Ronu_t > 0 dB. (14)

Therefore requirement for Ronu_t in this case is not necessary.

Regarding Class C, assuming determination level as no signal is equal to minimum sensitivity -10 dB, determination level as no signal = -33 dBm - 10 dB = -43 dBm.

Then,

+4 -32 - Ronu_t -15 < -43. (15)

We obtain,

Ronu_t > 0 dB. (16)

Therefore requirement for Ronu_t in this case is not necessary.

C.2.4.2 Case 2

Figure C.5 shows the path of reflectance signals. The following equation F shall be satisfied:

P_{Old} - Rdown - Iolt_r < (determination level as no signal) **[Equation F]**

Regarding Class B, assuming determination level as no signal is equal to minimum sensitivity -10 dB, determination level as no signal = -30 dBm - 10 dB = -40 dBm.

Then,

+2 -32 - Iolt_r < -40. (17)

We obtain,

Iolt_r > 10 dB. (18)

Regarding Class C, assuming determination level as no signal is equal to minimum sensitivity -10 dB, determination level as no signal = -33 dBm - 10 dB = -43 dBm.

Then,

+4 -32 - Iolt_r < -43. (19)

We obtain,

Iolt_r > 15 dB. (20)

C.3 Other case of ODN reflectance

The calculation method mentioned above is available for case that ODN reflectance is -19 dB. Table C.1 shows the requirement for optical parameters when minimum ORL of ODN is 32 dB and 19 dB.

WDM isolation parameter is implementation matter, and values concerning WDM isolation parameters in the table C.1 are just informative. FSAN specification includes ONU and OLT equipment reflectance. Considering the characteristic of the WDM, Ronu_t is equal to the reflectance of ONU measured at transmitter wavelength.

When ORL of ODN is 32 dB, ONU transmitter equipment reflectance shall be less than incident optical power. Therefore it shall be 6 dB which is available in an ordinary FP-LD module.

In the case that ORL of ODN is 19 dB, ONU transmitter equipment reflectance shall be less than 13 dB.

As mentioned above, maximum ONU transmitter equipment reflectance is sensitive to the value of ORL of ODN, which depends on the network built by the common carrier. In case that ORL of ODN is 32 dB and 19 dB, values of equipment reflectance for ONU transmitter in table C.1 are applicable. In other case, the appropriate value is derived by means of calculation method mentioned above.

Table C.1: Values for ONU transmitter equipment reflectance

Min ORL of ODN	Class	Optical parameters	Required characteristics					
			A (see note)	B (see note)	C (see note)	D (see note)	E (see note)	F (see note)
32 dB	B	WDM isolation for ONU receiver	10 dB					
		WDM isolation for ONU transmitter						
		WDM isolation for OLT receiver				10 dB		10 dB
		WDM isolation for OLT transmitter			NA			
		Equipment reflectance for ONU transmitter		NA			NA	
	C	WDM isolation for ONU receiver	15 dB					
		WDM isolation for ONU transmitter						
		WDM isolation for OLT receiver				15 dB		15 dB
		WDM isolation for OLT transmitter			NA			
		Equipment reflectance for ONU transmitter		NA			NA	
19 dB	B	WDM isolation for ONU receiver	23 dB					
		WDM isolation for ONU transmitter						
		WDM isolation for OLT receiver				23 dB		23 dB
		WDM isolation for OLT transmitter			9 dB			
		Equipment reflectance for ONU transmitter		12 dB			13 dB	
	C	WDM isolation for ONU receiver	28 dB					
		WDM isolation for ONU transmitter						
		WDM isolation for OLT receiver				28 dB		28 dB
		WDM isolation for OLT transmitter			9 dB			
		Equipment reflectance for ONU transmitter		12 dB			13 dB	

NOTE: A, B, C, D, E, and F represent equation A, equation B, equation C, equation D, equation E, and equation F, respectively.

Annex D (informative): Ranging flow diagrams in ATM PON

D.1 Ranging flow in the ONU (example)

Figure D.1 (1/7 to 7/7) indicates an example ranging flow in the ONU. It is not intended to specify the ranging procedure and is only shown for information.

The ranging flow diagrams shown here are examples of the normal operation of the ranging procedure. To simplify the diagrams, the effects of alarms (such as LOS, LCD, OAML and FRML) are not shown. The effects of certain messages (such as Disable_serial_number and Deactivate_PON_ID) are also not shown.

D.2 Ranging flow in the OLT (example)

Figure D.2 (1/7 to 7/7) indicates an example ranging flow in the OLT. It is not intended to specify the ranging procedure and is only shown for information.

The ranging flow diagrams shown here are examples of the normal operation of the ranging procedure. To simplify the diagrams, the effects of alarms (such as LOS, LCD, OAML and FRML) are not shown. The effects of certain messages (such as Disable_serial_number and Deactivate_PON_ID) are also not shown.

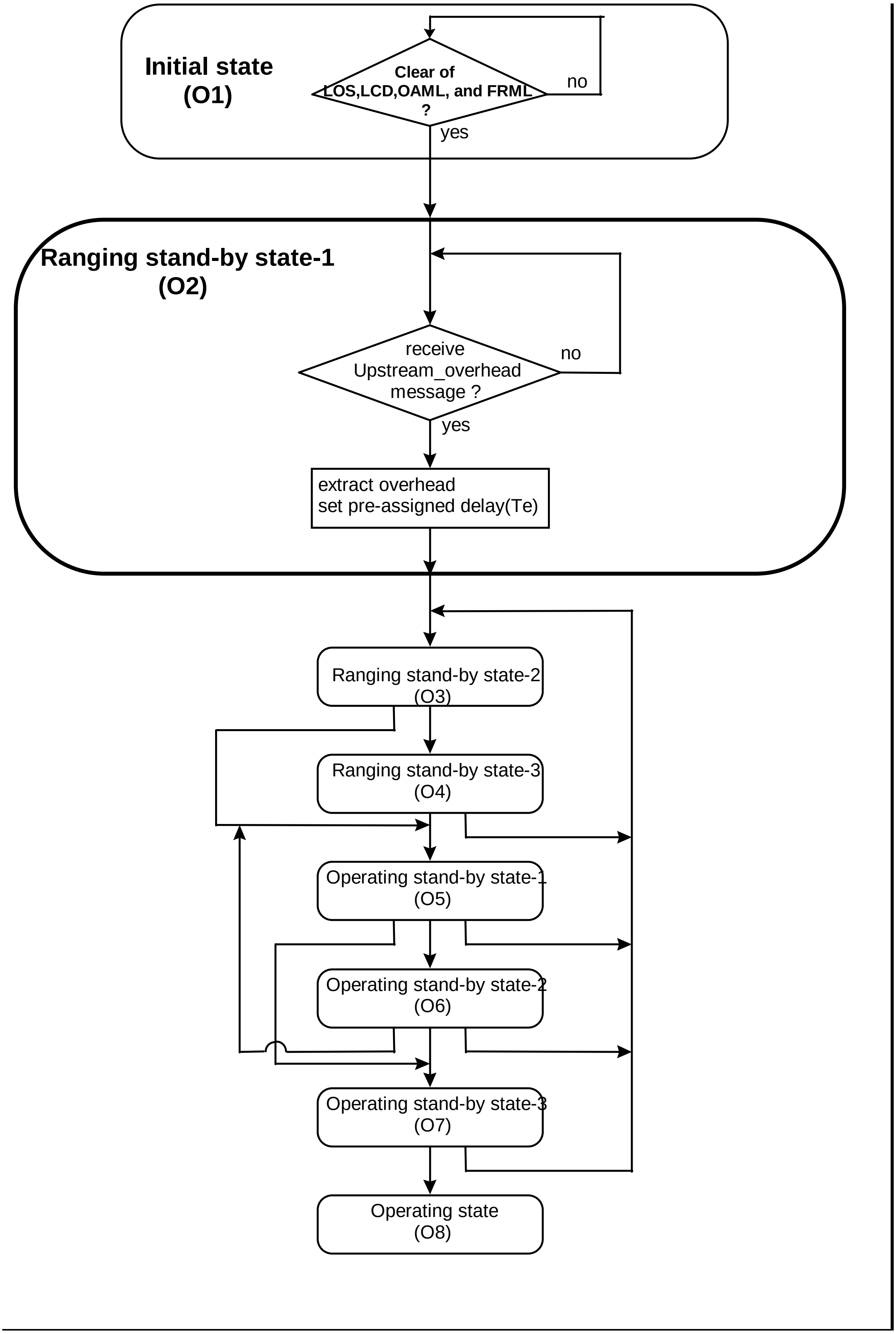


Figure D.1: Ranging flow [ONU] (Example) (1/7)

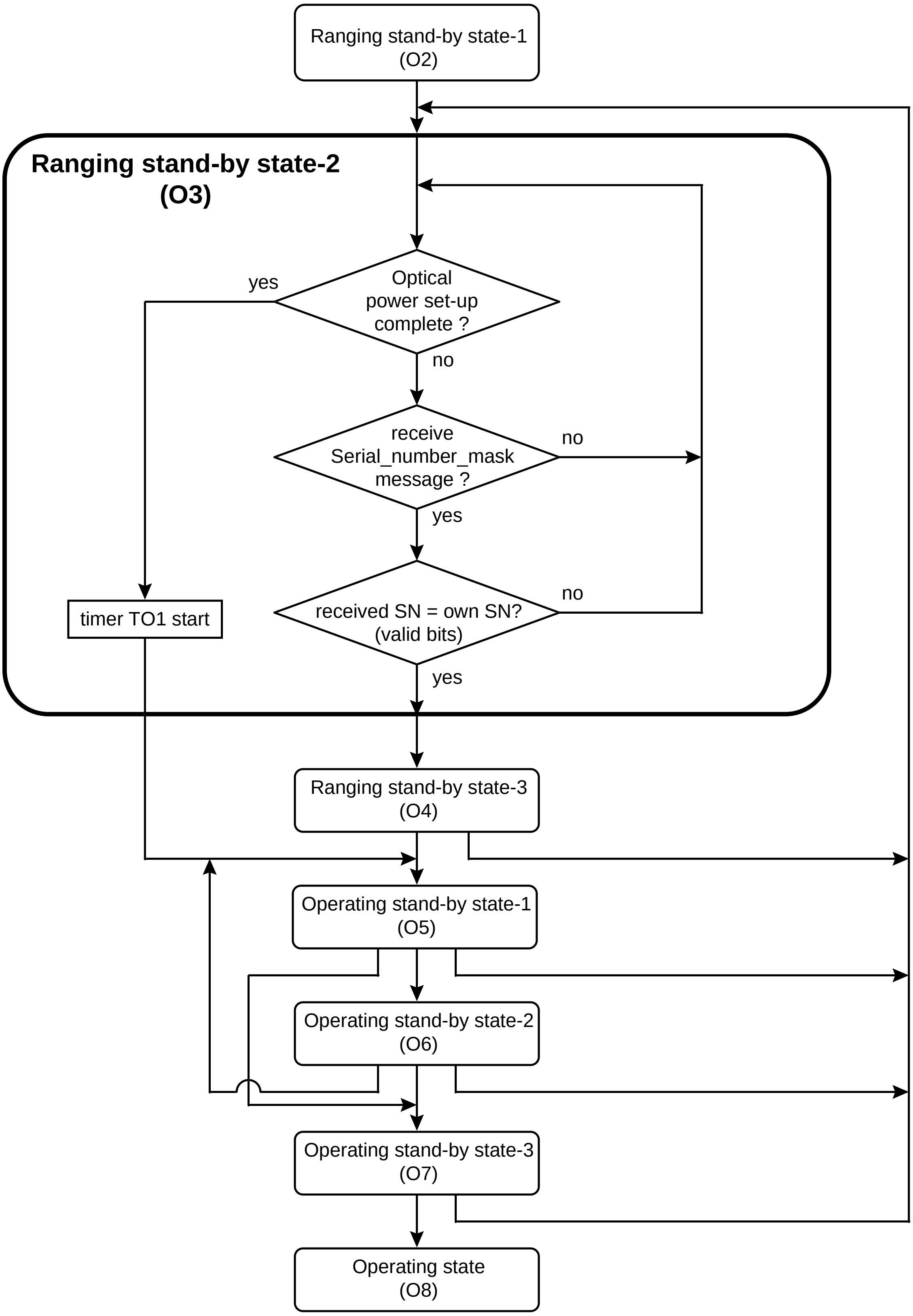


Figure D.1: Ranging flow [ONU] (Example) (2/7)

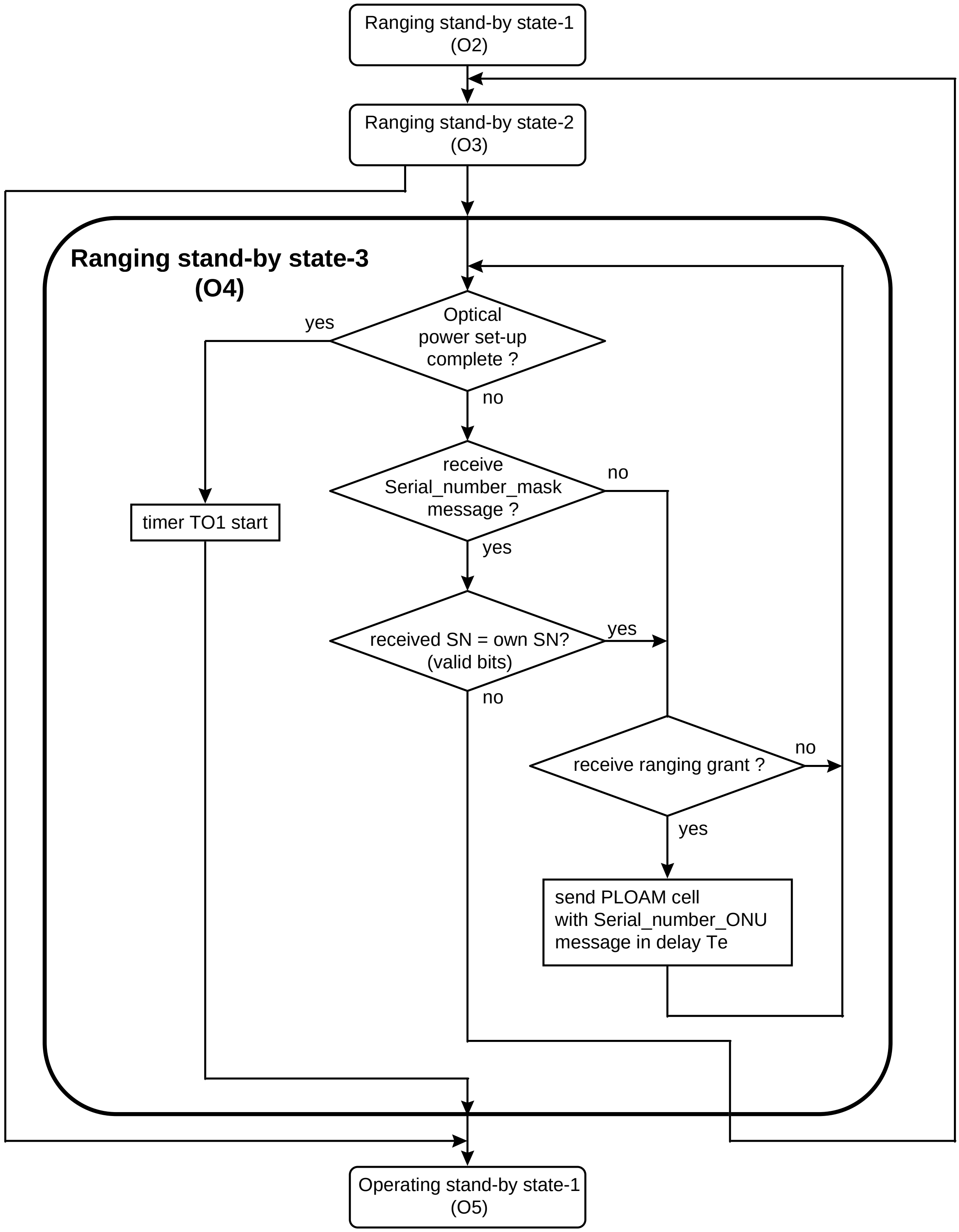


Figure D.1: Ranging flow [ONU] (Example) (3/7)

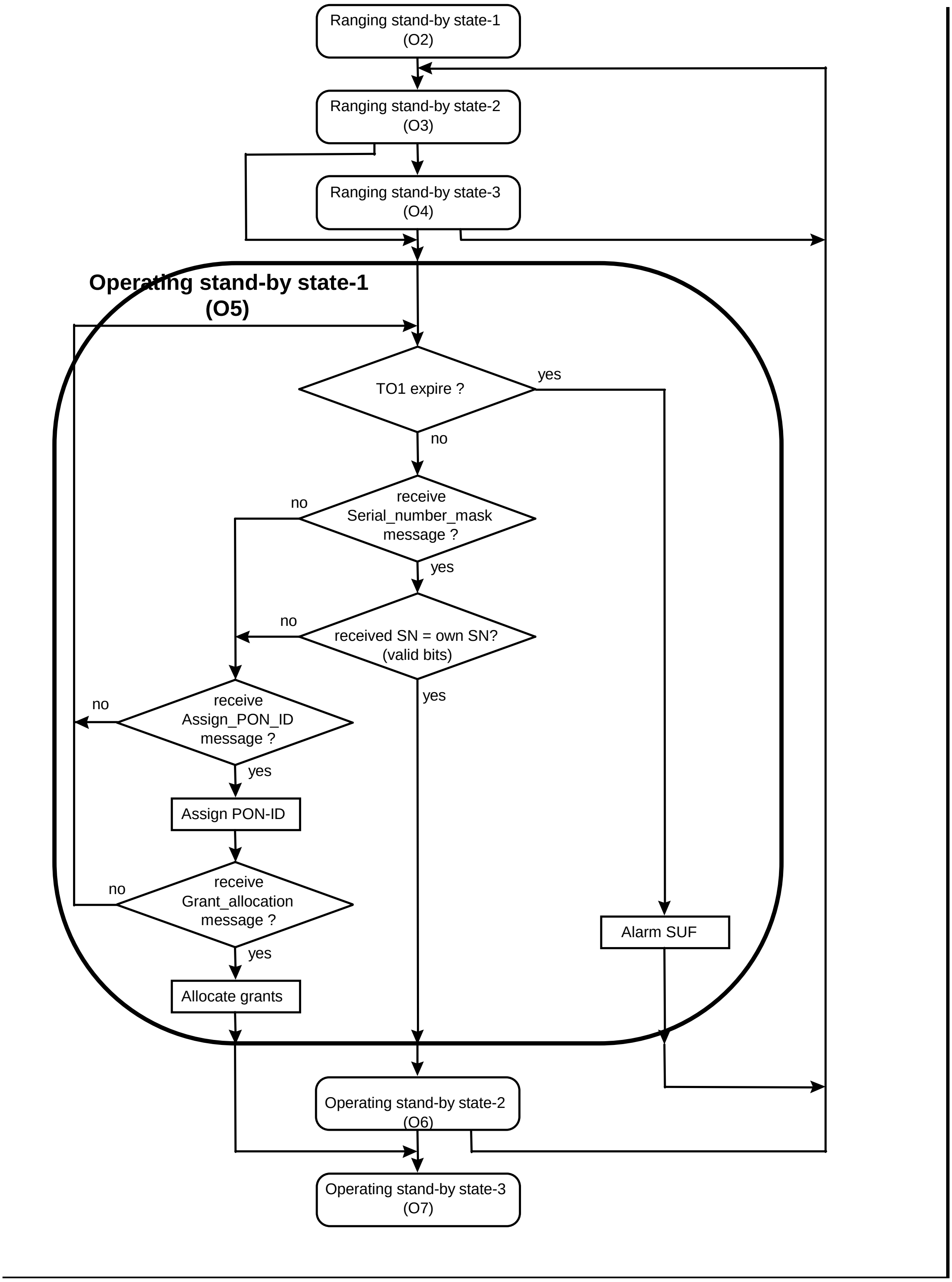


Figure D.1: Ranging flow [ONU] (Example) (4/7)

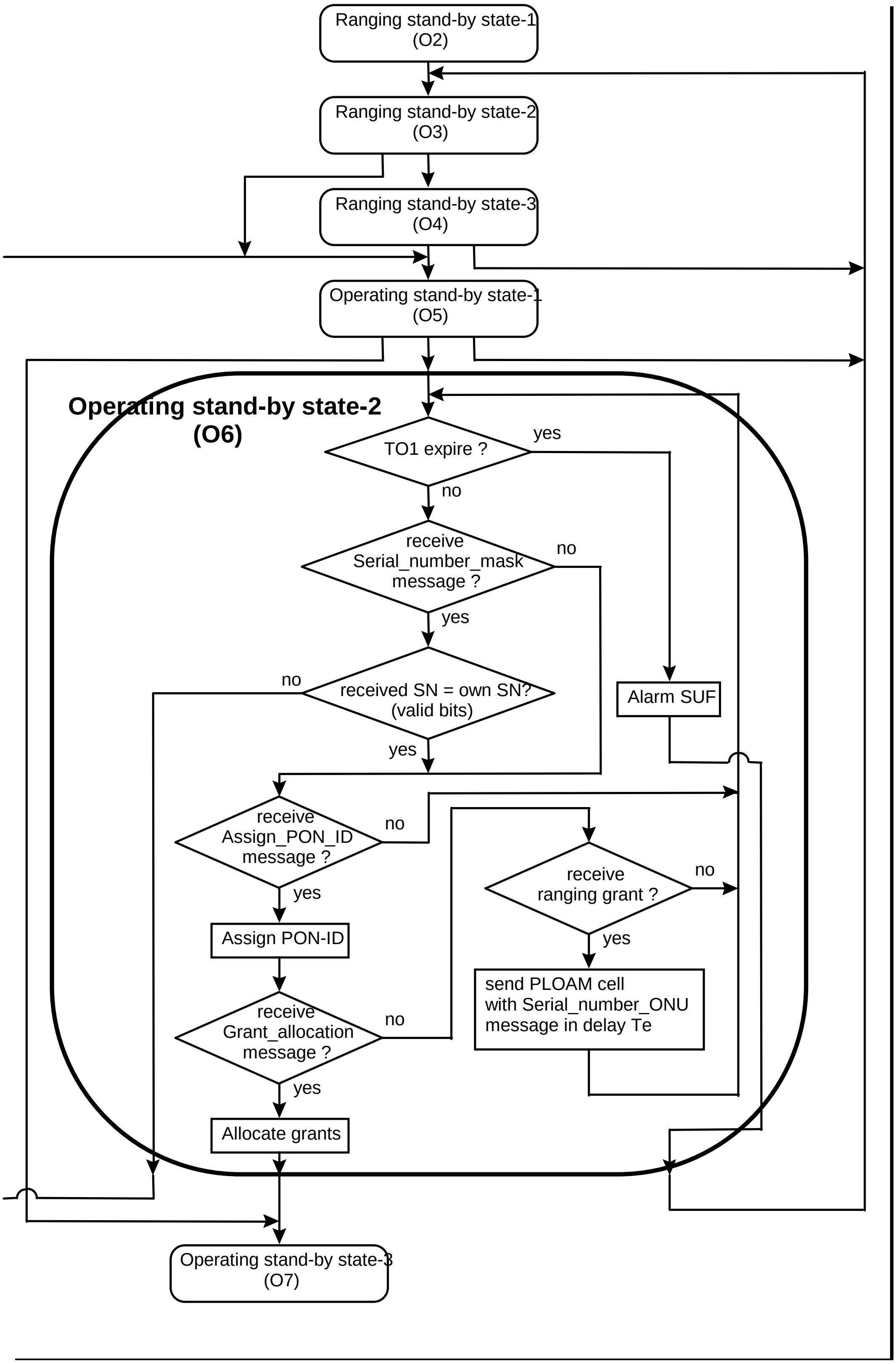


Figure D.1: Ranging flow [ONU] (Example) (5/7)

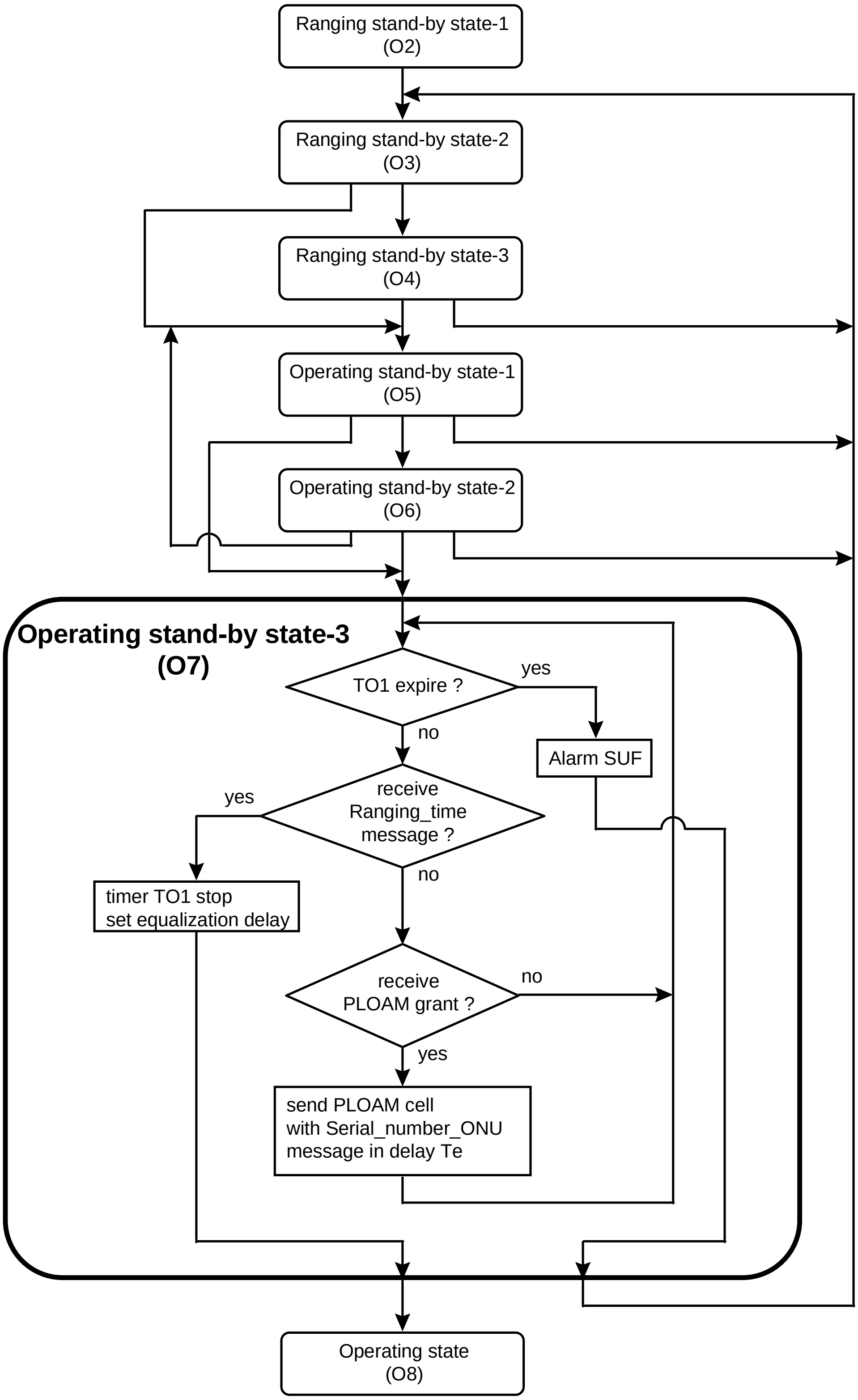


Figure D.1: Ranging flow [ONU] (Example) (6/7)

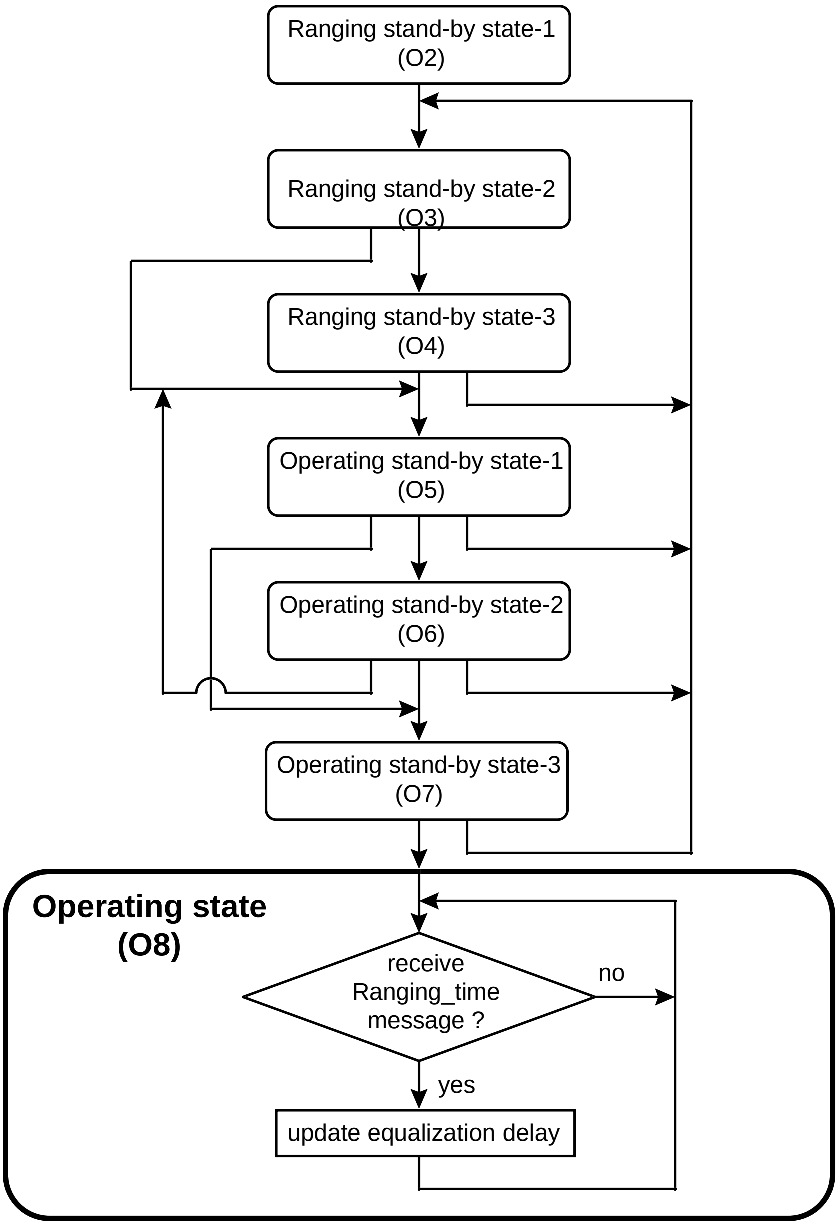


Figure D.1: Ranging flow [ONU] (Example) (7/7)

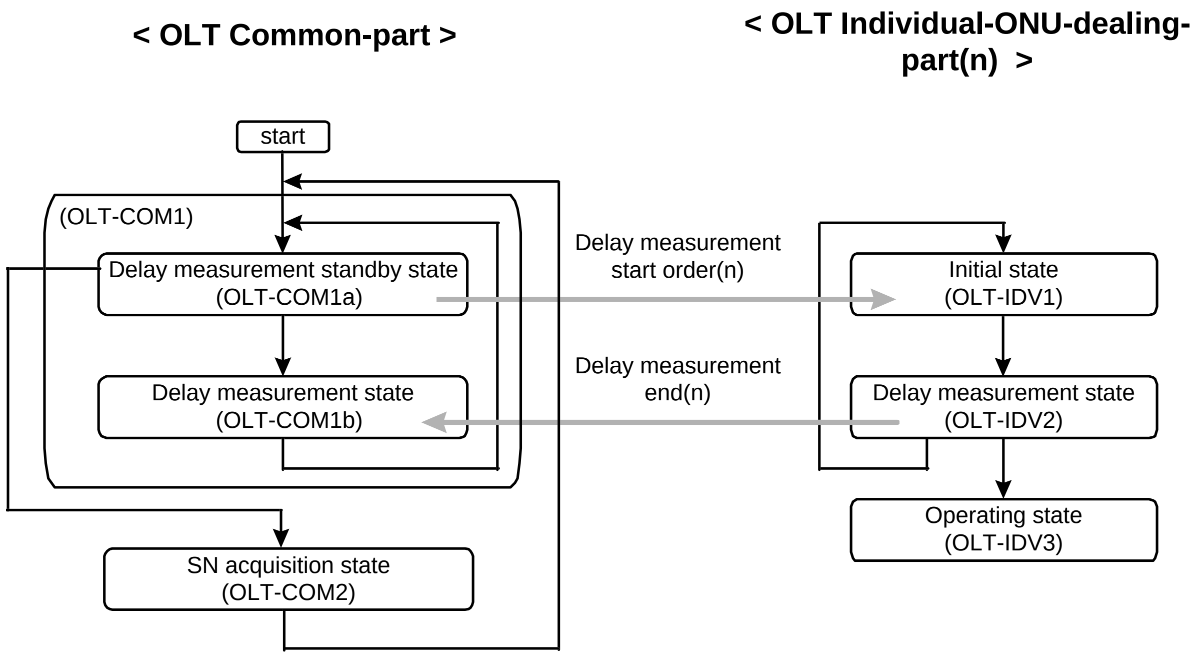


Figure D.2: Ranging flow [OLT] (Example) (1/7)

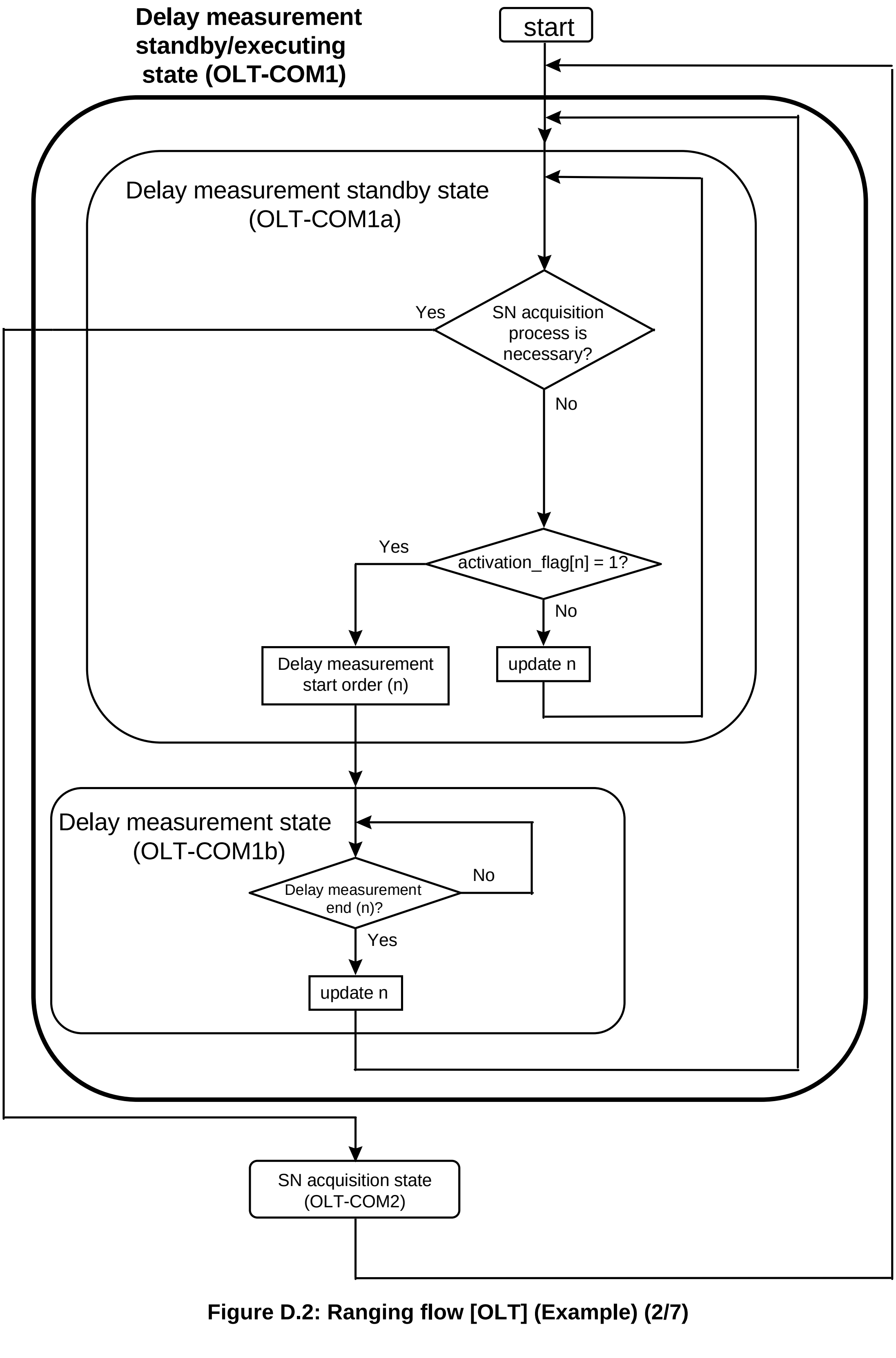


Figure D.2: Ranging flow [OLT] (Example) (2/7)

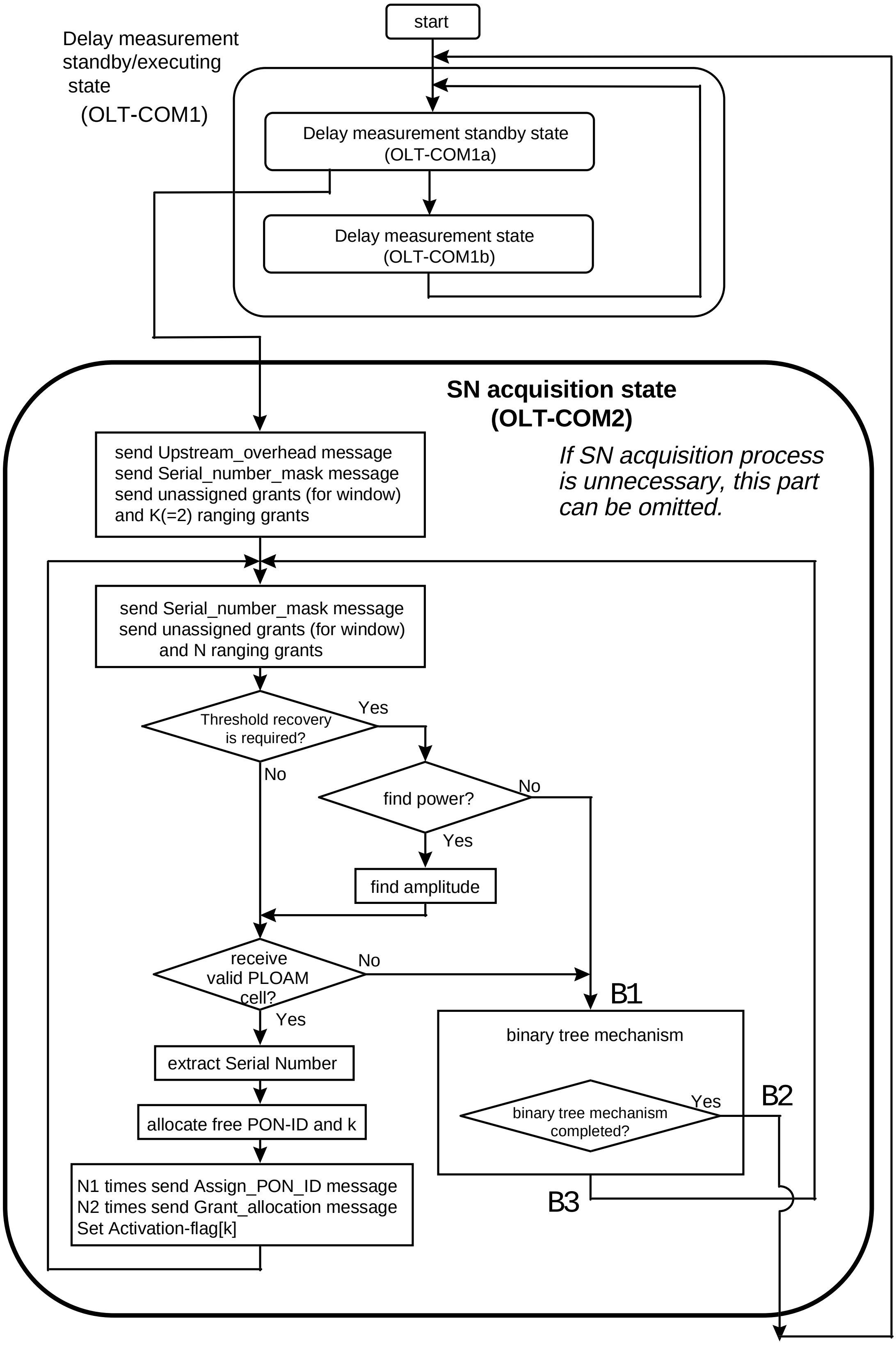
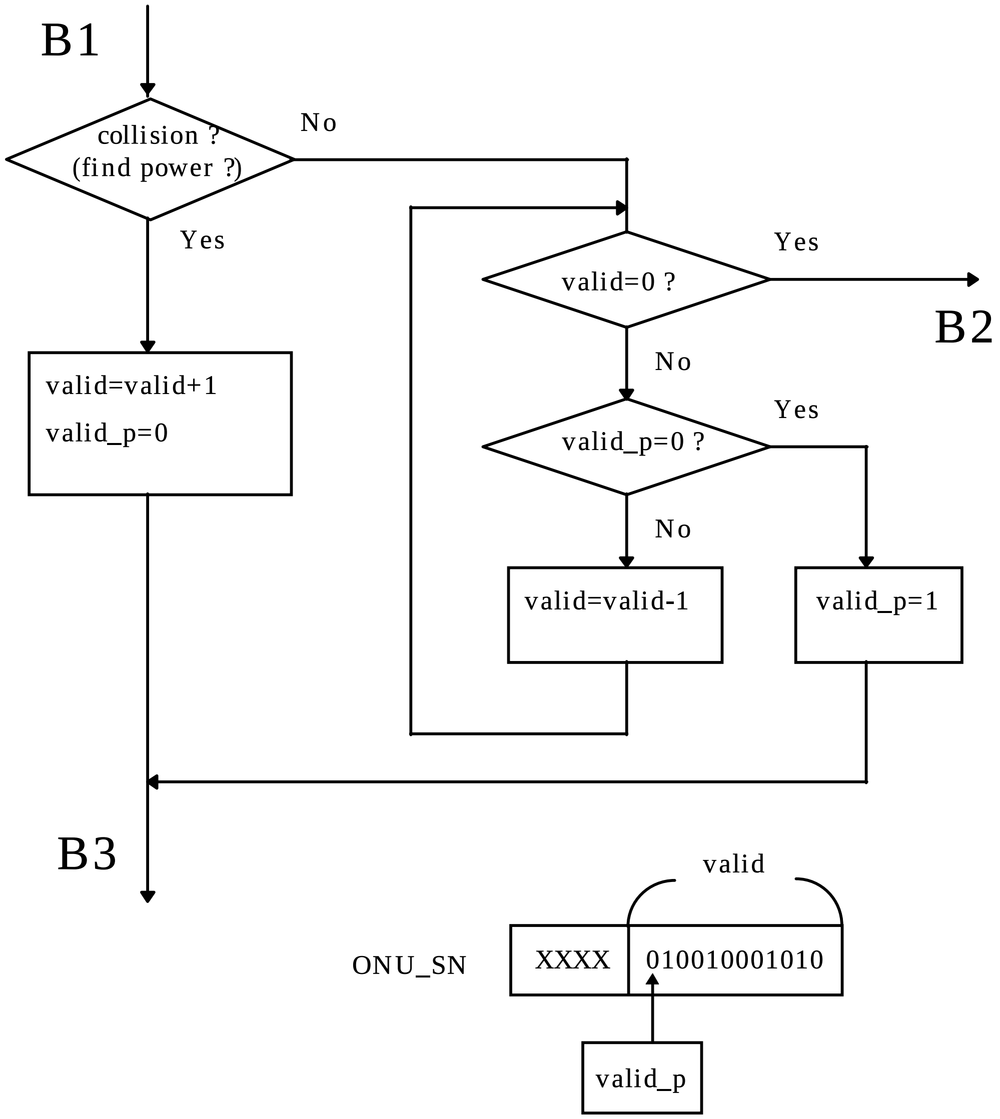


Figure D.2: Ranging flow [OLT] (Example) (3/7)



NOTE: The points of B1, B2, and B3 correspond to the points of B1, B2, and B3 in the figure C-2 Ranging flow [OLT](Example) (3/7) respectively.
"valid" means the number of valid bits of ONU serial number.
"valid_p" indicates the bit of the most significant bit of valid bits.

Figure D.2: Ranging flow [OLT] (Example) (4/7)

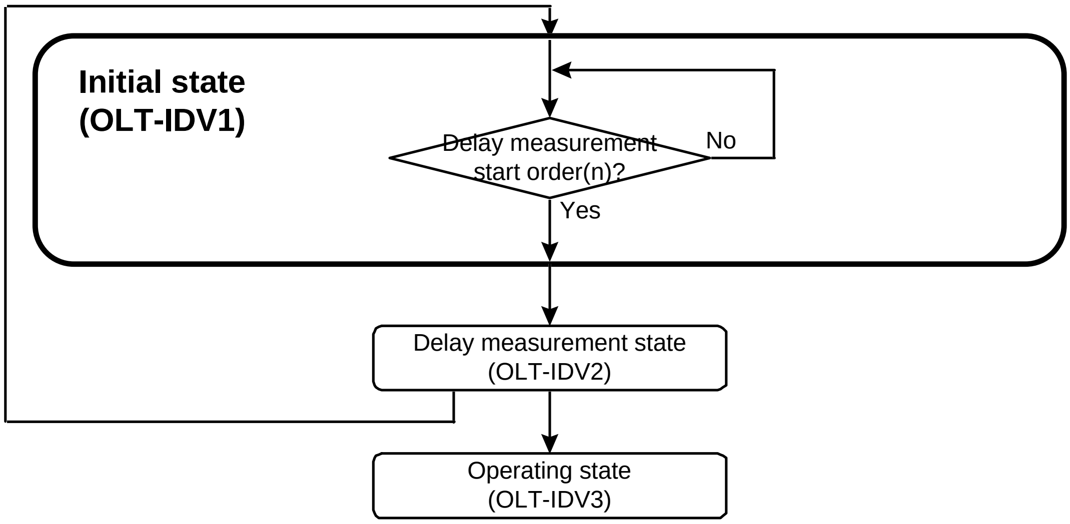


Figure D.2: Ranging flow [OLT] (Example) (5/7)

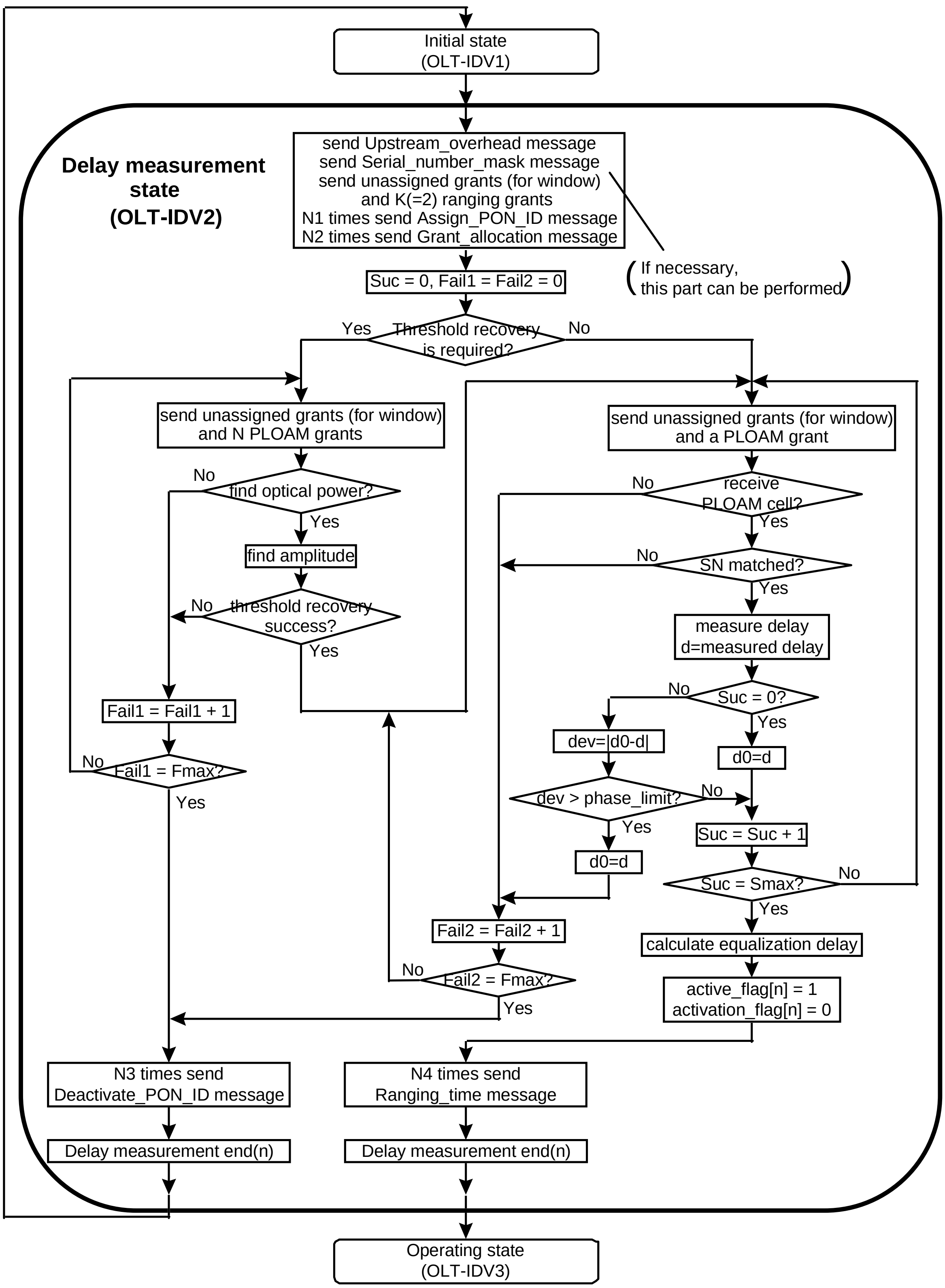
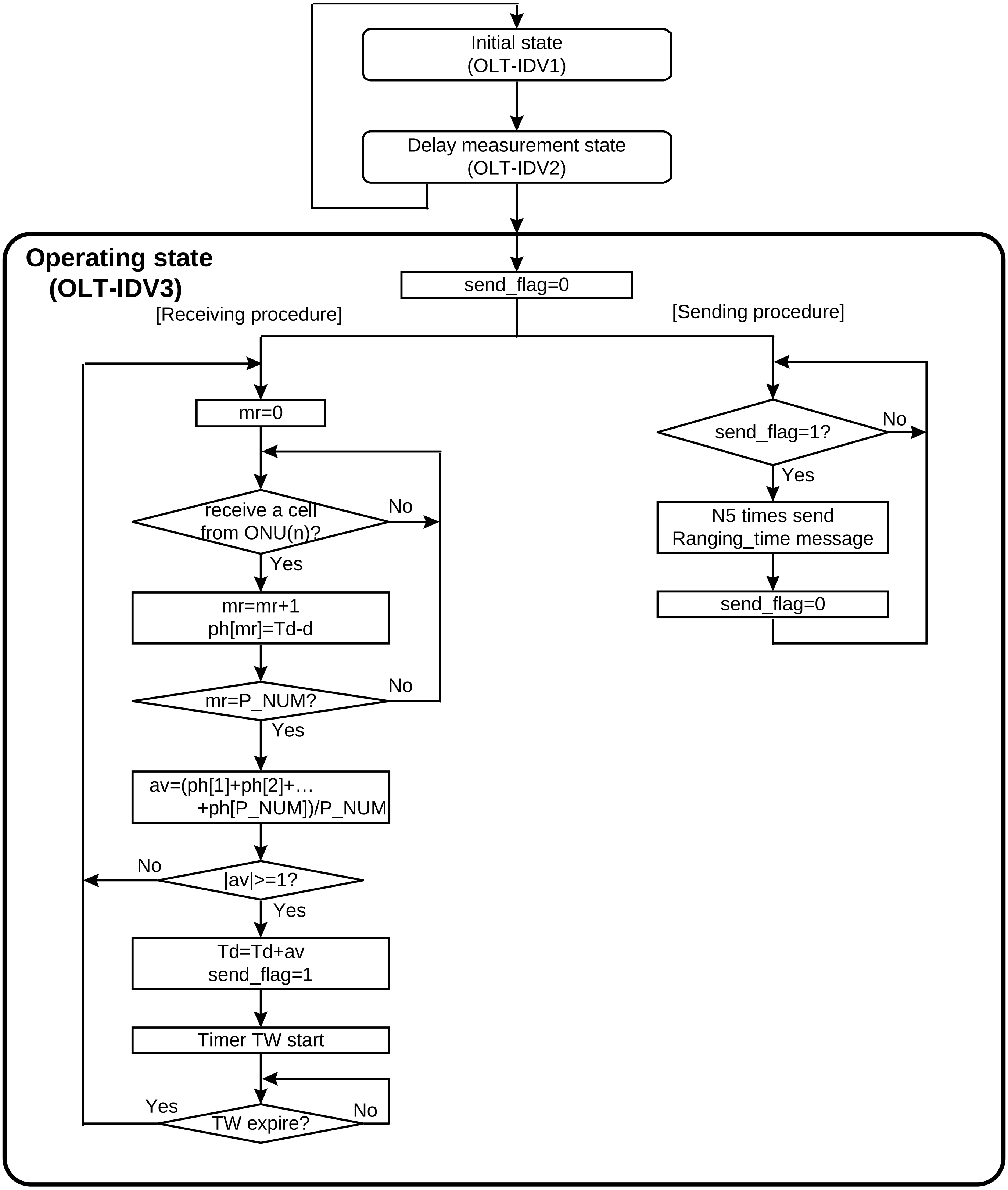


Figure D.2: Ranging flow [OLT] (Example) (6/7)



mr : counter of received cells from ONU(n)
ph[j] : deviation value of phase difference
P_NUM : number of phase measurement
av : average of ph[1], ph[2],...,ph[P_NUM]

Td : currently used equalization_delay
d : newly measured equalization_delay
TW : timer for phase difference measurement
send_flag : transmission requirement flag of Ranging_time message

Figure D.2: Ranging flow [OLT] (Example) (7/7)

Annex E (informative): Access Network Survivability

E.1 Introduction

From the view point of administration of the access network, the protection architecture of the ATM PON is considered to enhance the reliability of the access networks. However, the protection shall be considered as an optional mechanism, because its implementation depends on the realization of the economical system.

The present document presents some possible duplicated configurations and the related requirements as examples of ATM PON to stimulate further discussion. In addition, the required OAM message for the protection is mentioned.

E.2 Possible switching types

There are two types of protection switching; (i) automatic switching and (ii) forced switching, which are analogous to SDH systems. The first one is triggered by the fault detection, such as loss of signal, loss of frame, signal degrade (BER becomes worse than the pre-determined threshold), and so on. The second one will be activated by administrative events, such as fibre re-routing, fibre replacement, etc. Both types should be possible in the ATM PON system, if required, even though they are optional functions. The switching mechanism is generally realized by the OAM function, therefore, the required OAM information field should be reserved in the PLOAM cells.

Figure E.1 shows a duplicated system model for the access network. The relevant part of the protection in the ATM PON system should be a part of the protection between the ODN interface in the OLT and the ODN interface in the ONU via the ODN, excluding the SNI redundancy in the OLT.

E.3 Possible duplicated ATM-PON configurations and characteristics

There can be several types of duplicated ATM PON system, as shown in figure E.2 (a) to (d). The control protocols for each configuration should be specified independently with each other.

For example, any switching protocol is not required for OLT/ONU in figure E.2 (a), since the switching is only applied for the optical fibres. Also in figure E.2 (b), any switching protocol is not required, since the switching is carried out only in the OLT.

E.3.1 Configuration examples

E.3.1.1 Type A

The first configuration doubles only the optical fibres, as shown in figure E.2 (a). In this case, the ONUs and OLTs are singular.

E.3.1.2 Type B

The second configuration example (figure E.2 (b)) doubles the OLTs and optical fibres between the OLTs and the optical splitter, and the splitter has two input/output ports on the OLT side. This configuration reduces the cost of duplicating the ONUs, although only the SLT side can be recovered.

E.3.1.3 Type C

The third configuration example (figure E.2 (c)) doubles not only the OLT side facilities but also the ONU side. In this configuration, failure at any point can be recovered by switching to the stand-by facilities. Therefore, the full duplication cost enables a high reliability.

E.3.1.4 Type D

If the ONUs are installed in the customer buildings, the in-house wiring may or may not be duplicated. Additionally, if each ONU is owned by different users, the reliability requirement depends on each user and only a limited number of ONUs may have the duplicated configuration. Based on this consideration, the last one (figure E.2 (d)) permits a partial duplication on the ONU side. This figure shows an example where there are duplicated ONU#1 and single ONU#N. Its key principles are:

1) using double N:2 optical splitters to connect PON LT(0) in the ONU#1 to splitter N(0) and PON LT(1) in the ONU#1 to splitter N(1);

2) connecting PON LT in the ONU#N to either optical splitter, because it is single;

3) using double 2:1 optical splitters to connect PON LT(0) in the OLT to splitter(0) and PON LT(1) in the OLT to splitter(1);

4) connecting double N:2 optical splitters and double 2:1 optical splitters, where one port of splitter(1) is connected to splitter N(0), and one port of splitter(0) to splitter N(1);

5) using the cold stand-by method in both OLT and ONUs to avoid the optical signal collision from PON LT(0) and PON LT(1) in the OLT, or PON LT(0) an PON LT(1) in the ONU #1.

E.3.2 Characteristics

Type A: In this case, the signal loss or even cell loss is inevitable in the switching period. However, all the connections between the service node and the terminal equipment should be held after this fibre switching.

Type B: This configuration requires cold stand-by of the spare circuit in the OLT side. In this case, the signal loss or even cell loss is, in general, inevitable in the switching period. However, all the connections supported between the service node and the terminal equipment should be held after this switching.

Type C: In this case, the hot stand-by of the spare receiver circuits is possible in both ONU and OLT sides. In addition, the hit-less switching (without cell loss) is also possible in this configuration.

Type D: The characteristics of this type is the same as Type B.

E.4 Requirements

a) The protection switching function should be optional.

b) Both automatic protection switching and forced switching are possible in the ATM PON system, if required, even though they are optional functions.

c) All the configuration examples of clause E.3 will be possible, even though they are optional functions.

d) The switching mechanism is generally realized by the OAM function, therefore, the required OAM information field shall be reserved in the PLOAM cells.

e) All the connections supported between the service node and the terminal equipment should be held after this switching.

Regarding requirement e), one implementation of the POTS service node (exchange) requires the cell loss period to be less than 120 msec. If the cell loss period becomes longer than that, the service node disconnects the call, and the call-set-up is required again after the protection switching. Since ATM PON supports the emulation of the conventional services, such as POTS and ISDN, this value should be taken into consideration.

E.5 Required information fields for PLOAM cell

According to the analogy of the SDH system, the protection switching requires less than ten codes to be used for both upstream and downstream, which will be realized by the field of the PLOAM cell. The field mapping of the PLOAM cell for the protection will be required to be defined.

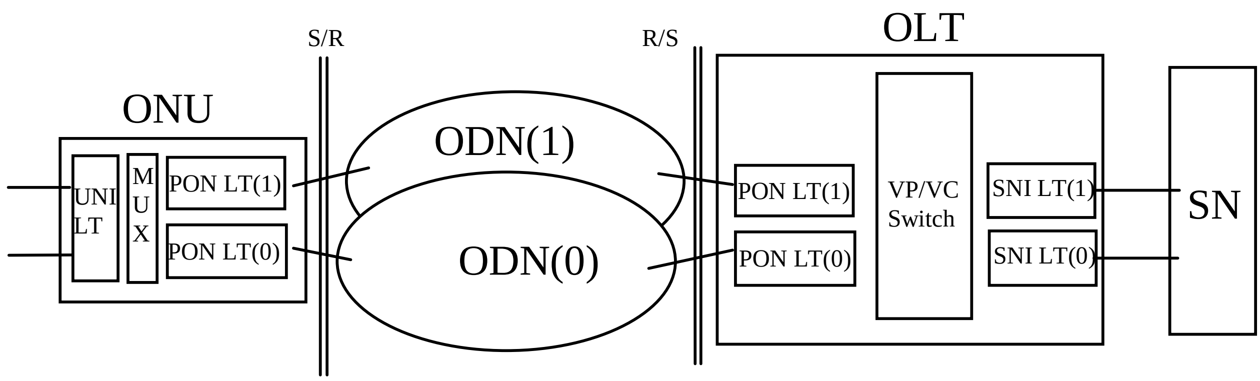
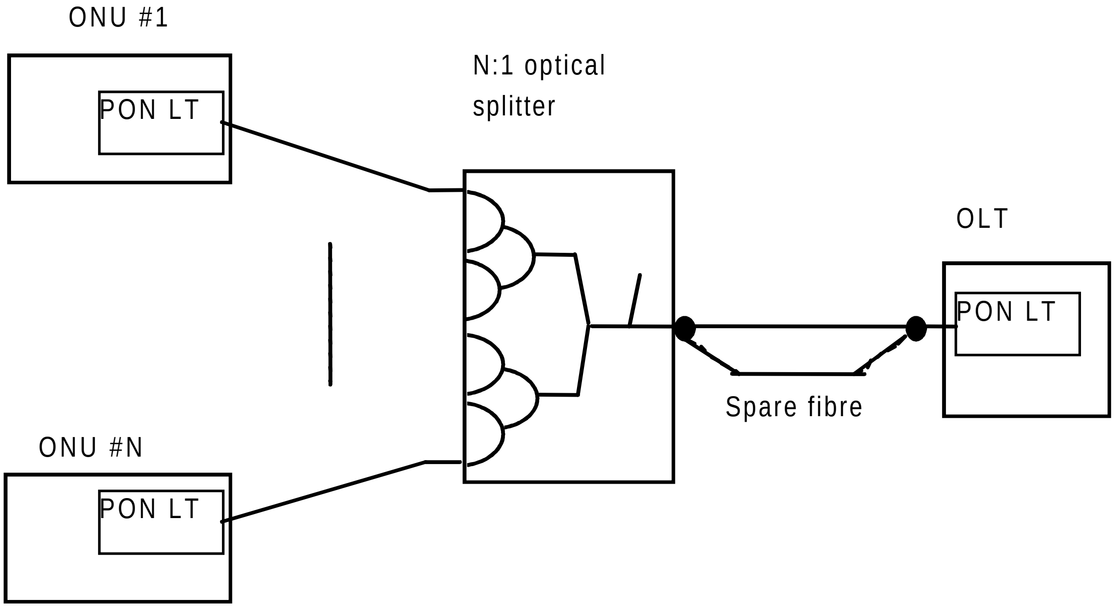
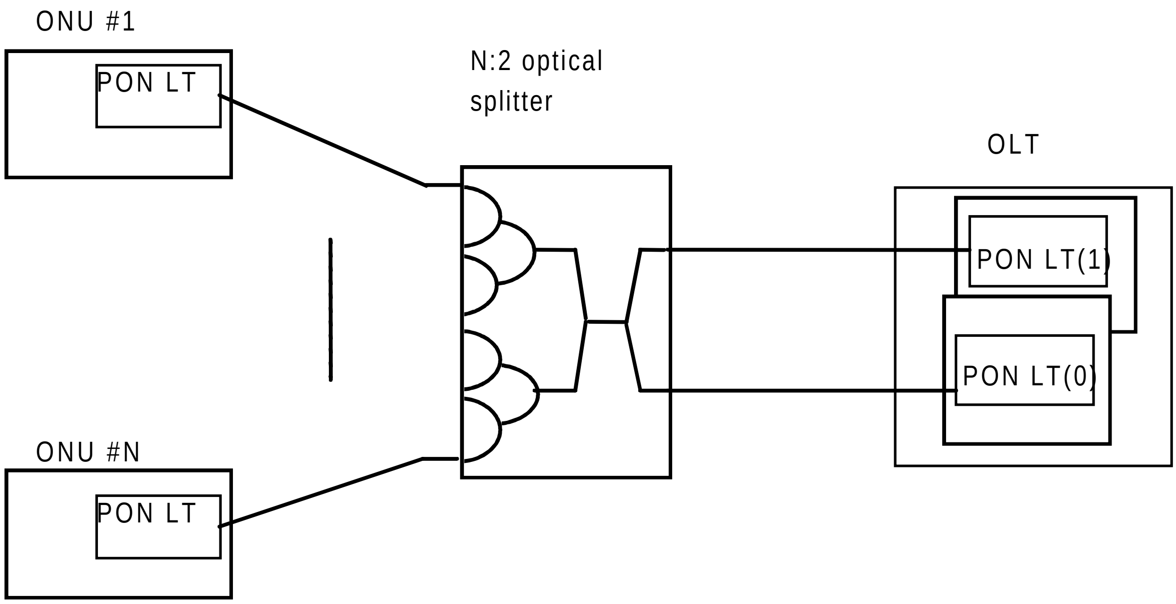


Figure E.1: Duplicated system model

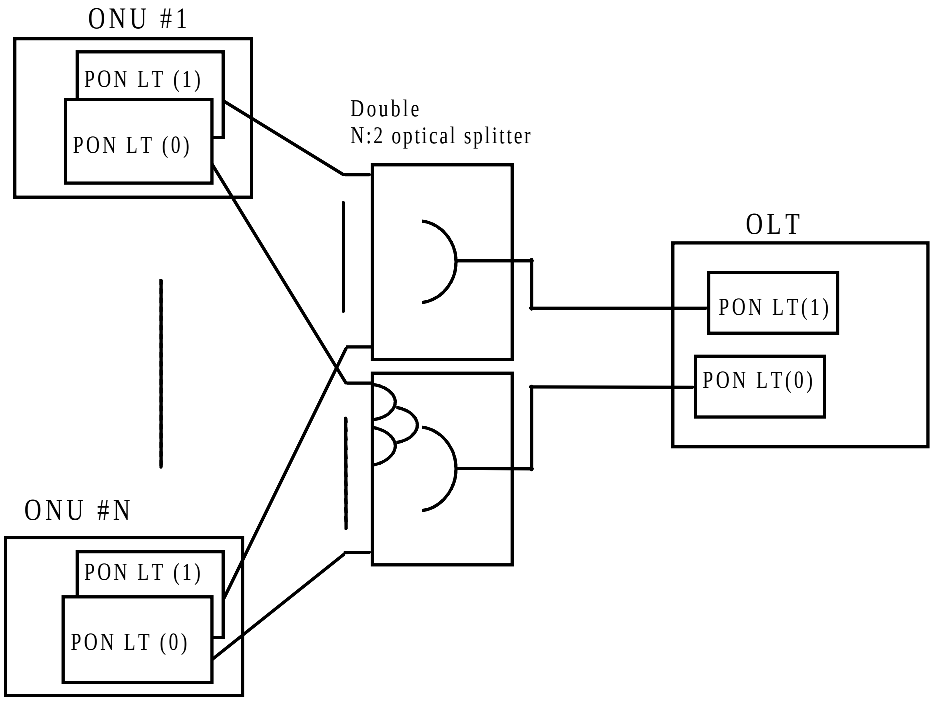


(a) Fibre duplex system

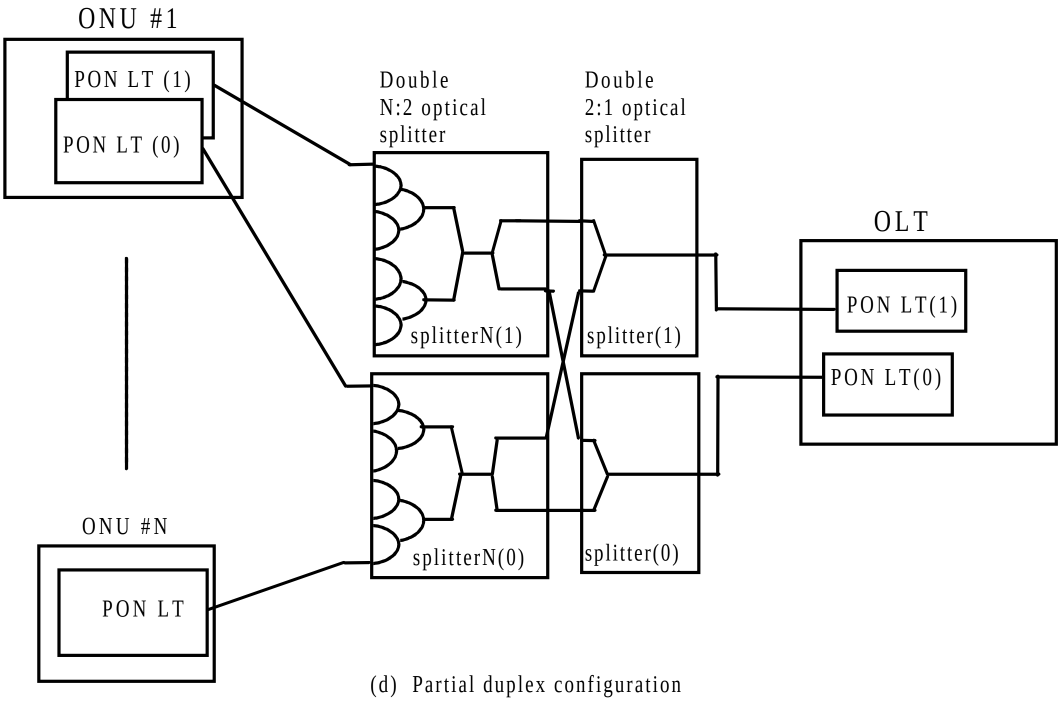


(b) OLT-only duplex system

Figure E.2: Duplicated ATM PON system (1/2)



(c) Full duplex system



(d) Partial duplex configuration

Figure E.2: Duplicated ATM PON system (2/2)

Annex F (informative): Functional architecture of alternatives for the evolution of the ODN

The functional architecture depicted in figure F.1 shows a number of possible alternatives for the evolution of the ODN.

The support of both broadband (including distributive and interactive) and narrowband services through the same ODN may be achieved at different layers, and consequently with different degrees of integration.

Starting from the lowest layer, the support of different services can be achieved using the same physical infrastructure (same ducts, same fibre ribbon) but different fibres; this is shown at the Medium Layer. The low level of integration implies the use different transmission systems for different services.

The second alternative is given by the use of different wavelengths, at the Optical Layer, still relying upon different transmission systems for the different services.

The third alternative is given by the use of a common optical transmission sub-system (same infrastructure, single optical wavelength, single frame structure), on top of which the Transmission Protocol Adaptation is able to accommodate both "bytes" (including possibly digitally coded video channels) and "ATM cells". The Transmission Protocol Adaptation function could also consist of an analogue modulation of a digital service or CCIR channel, as in an SCM system; the architectural element represented by the Transmission Protocol Adaptation is still valid: it is then evident how many forms such an element can take.

The fourth alternative is then given by the use of ATM (and, of course a common optical transmission sub-system, single fibre format, single Transmission Protocol Adaptation, the ATM TPA) as a common bearer for all the other types of services: the architecture includes Virtual Path and Virtual Channel layers, on top of which services are supported through the appropriate ATM Adaptation layer.

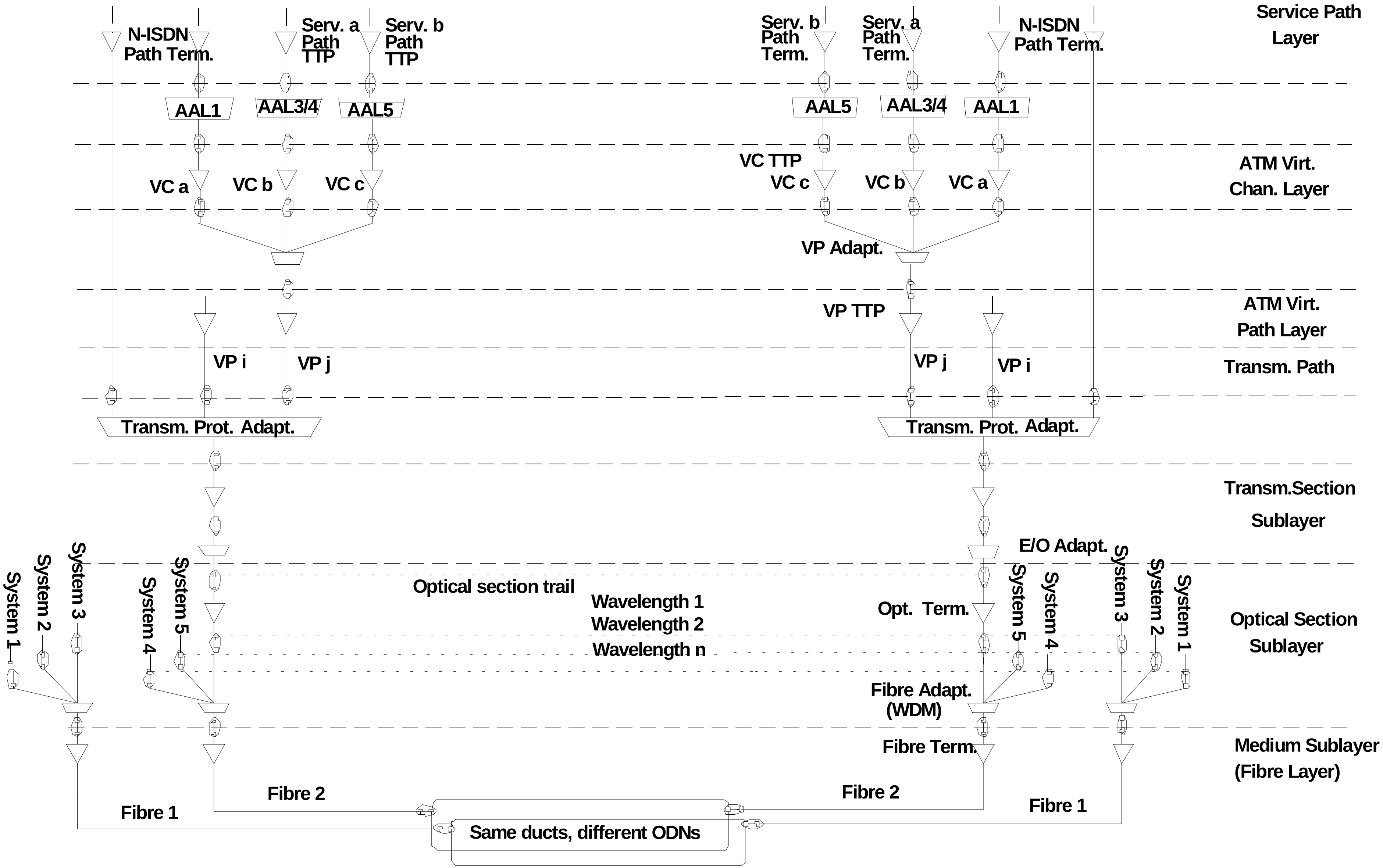


Figure F.1: Functional architecture of the possible ODN evaluations

Annex G (informative): Evolution of OAN based on HFC passband transmission systems

The discussion in this clause relates to the main network elements of an HFC system, namely OLT, Fibre Node (ONU) and Network Interface Unit. Two types of HFC systems are considered:

1) those conforming to DVB specifications, excluding upstream transmission (the cases of DTMF or other POTS arrangements for upstream transmission are not considered): downstream transmission is based on an MPEG-2 transport stream (TS), as in EN 300 429 [55];

2) those conforming to DAVIC, including upstream transmission, based on TDMA for access to the assigned bandwidth, and QPSK modulation (DAVIC 1.0 part 8) [56].

G.1 Reference configurations

The reference configurations in this clause show the distinct physical elements of each different HFC system, their contradistinctive main functions and interfaces. They are shown to facilitate the understanding of the corresponding functional models, which are more detailed.

G.1.1 HFC distributive system

The reference configuration of a distributive system (which only transports user data in the downstream direction, i.e. in the direction from service node to user) is shown in figure G.1. This also shows the typical internal partitioning of the main element functions.

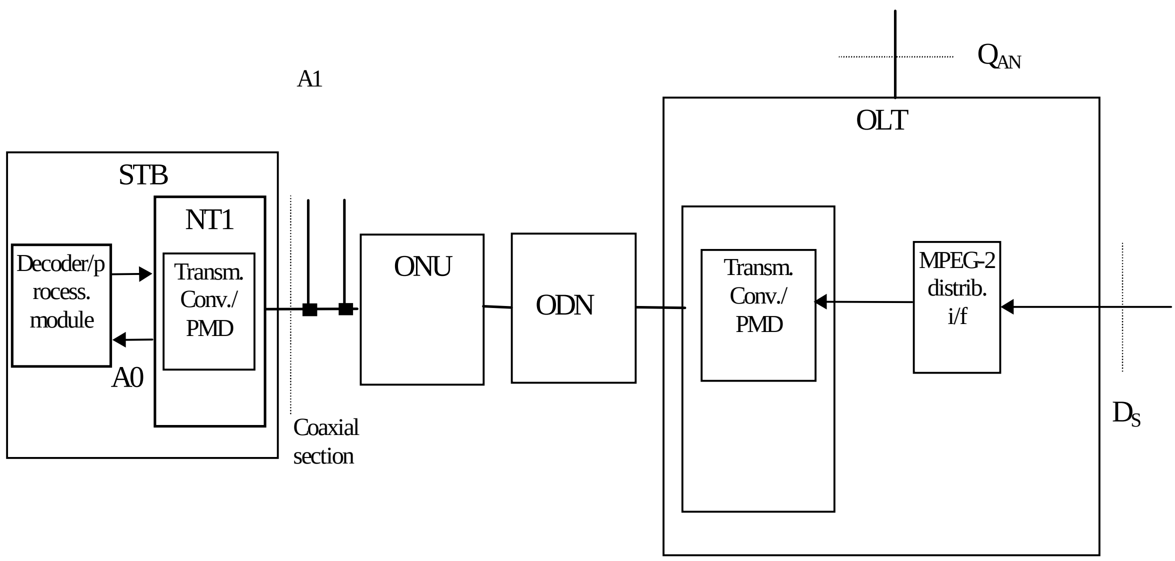


Figure G.1: Reference configuration for an HFC distributive system

The HFC OLT is provided only with the interface D_S toward the distributive head end, and is composed of two main functional blocks, the distributive interface termination functions and the AN specific physical layer functions.

The following open questions should be considered:

- whether HFC distributive systems should be considered for standardization;
- what sort of maintenance functions have to be implemented (upstream transmission is required to implement maintenance functions, as well as downstream features to implement performance monitoring and alarm detection);
- whether Service Information insertion and Conditional Access management shall be performed at the HFC ONU (these are not shown in the reference configuration);
- whether an NT is present in the configuration, and if present, what functions it performs.

G.1.2 HFC MPEG-2 based system

This is a bidirectional system using an MPEG-2 TS for the digital part of the transmission convergence over the access network. The relevant reference configuration is given in figure G.2.

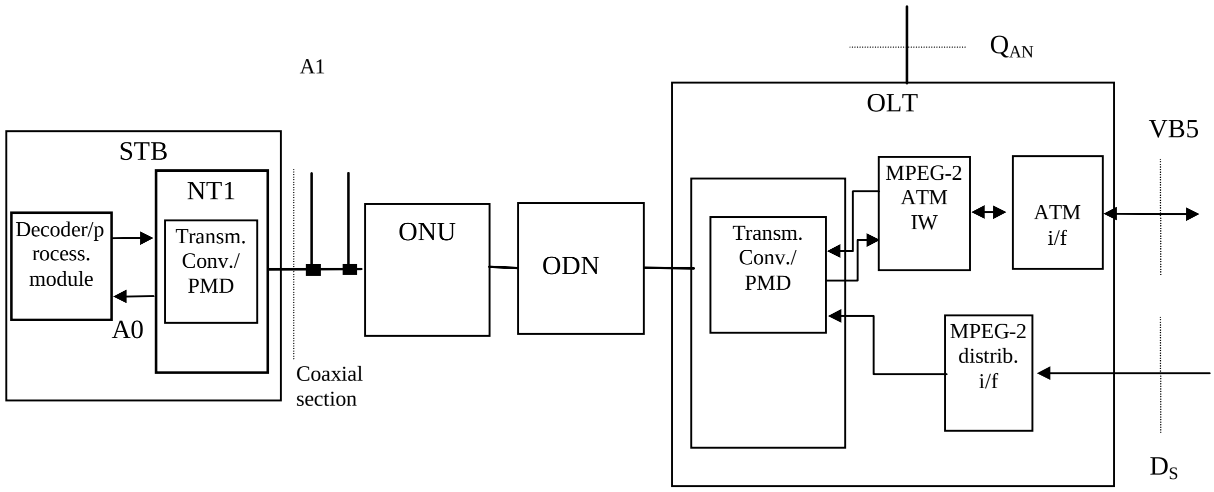


Figure G.2: Reference configuration for an HFC MPEG-2 based system

The OLT includes the following main blocks:

- VB5 ATM termination functions, providing interoperability with the ATM switch;
- distributive interface termination functions for interoperability with the OLT;
- ATM/MPEG-2 interworking functions, terminating the ATM connection and converting them in MPEG-2 TS elementary streams;
- AN specific physical layer functions, enabling bidirectional transmission over the HFC based AN.

The HFC system includes in this case upstream transmission of user data, allowing provisioning of interactive services. Such transmission is based on a TDMA protocol and QPSK modulation, according to DAVIC specifications. The downstream transmission of the necessary TDMA protocol information takes place using a different carrier with respect to those used for user information.

Again, some open issues may be considered:

- the location of the NT and its functions;
- the location of the TB interface (and whether it corresponds to the A1 interface as defined in DAVIC);
- the full specification of the TDMA protocol (presently defined neither in DAVIC or elsewhere);
- the full specification of the ATM/MPEG-2 interworking functions; current work is carried out in MPEG-2 and gathered in annex 2 of the DSM-CC extension to the MPEG-2 standard (ISO/IEC JTC1/SC29/WG11 Doc. N0950) [57].

G.1.3 HFC ATM-based system

This is a bidirectional system using ATM for the transmission convergence of interactive services: distributive services may still be carried using MPEG-2 TSs over different carriers, as currently considered in IEEE 802.14 [58].

The relevant reference configuration is shown in figure G.3.

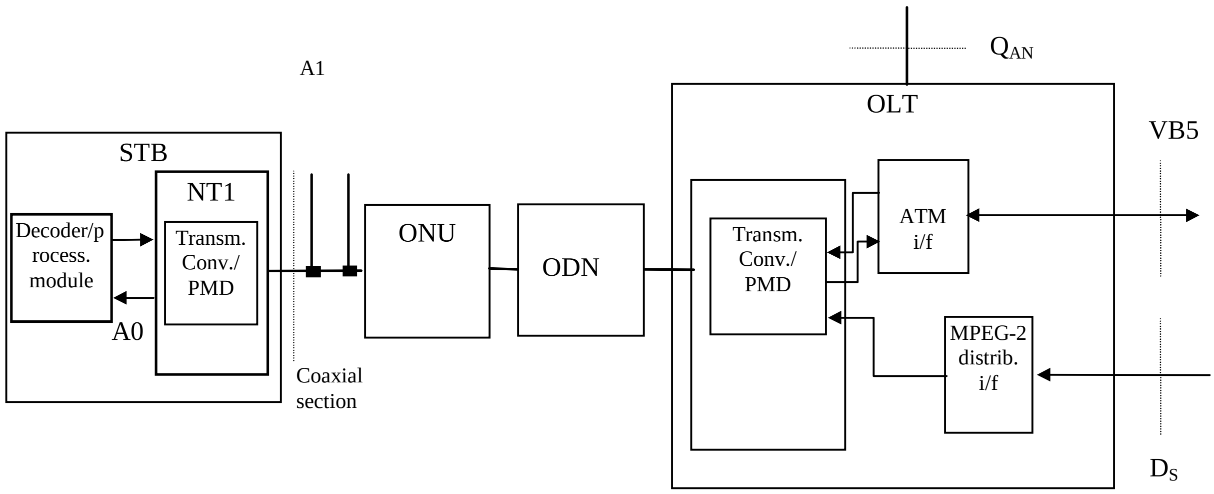


Figure G.3: Reference configuration for an HFC ATM based system

The OLT in this case includes the following main blocks:

- VB5 ATM termination functions, providing proper interoperation with the ATM switch;
- distributive interface termination functions for proper interoperation with the OLT;
- AN specific physical layer functions, enabling bidirectional transmission over the HFC based AN.

Multiplexing of ATM interactive services and distributive services takes place at the carrier level. Carrier assignment is defined in IEEE 802.14 [59].

DAVIC and ISO/IEC JTC1/SC29/WG11 are currently considering issues concerned with the use, support and transport in the AN of signalling for call control procedures, either instead or, or in conjunction with DSM-CC user-to-network primitives for session control and interworking between MPEG-2 resource management and ATM signalling. One opinion expressed is that session control is not required in an end-to-end ATM network, as it does not add any useful information for proper service dependent billing, and moreover such a type of billing could oppose ONP principles.

G.2 Functional architectures of HFC systems

The architectures shown in this clause require further work and are relevant only to the AN specific physical layer functions, certainly pertinent to TM3 for standardization. The other SN and NIU main functions (VB5 protocol termination, ATM/MPEG-2 interworking, transport of service information). particularly for the aspects relevant to the layers above the physical layer, need to be harmonized with SPS3 and TM1, and are not yet included, as they are rather complex, and not yet fully clarified in the case of interactive services.

G.2.1 HFC distributive system

The functional model for the downstream functions of an HFC distributive system is shown in figure G.4. Upstream functions in this case should be limited to the transport of OAM information, using another similar model, not yet produced, because such functions are not yet fully defined. NT functions are not shown, as an NT may not be appropriate in this case. Passive NT functions would then represented as a connection point in the medium layer. The optical section sublayer and the fibre sublayer are shown for completeness and are aligned with recent work carried out in RACE.

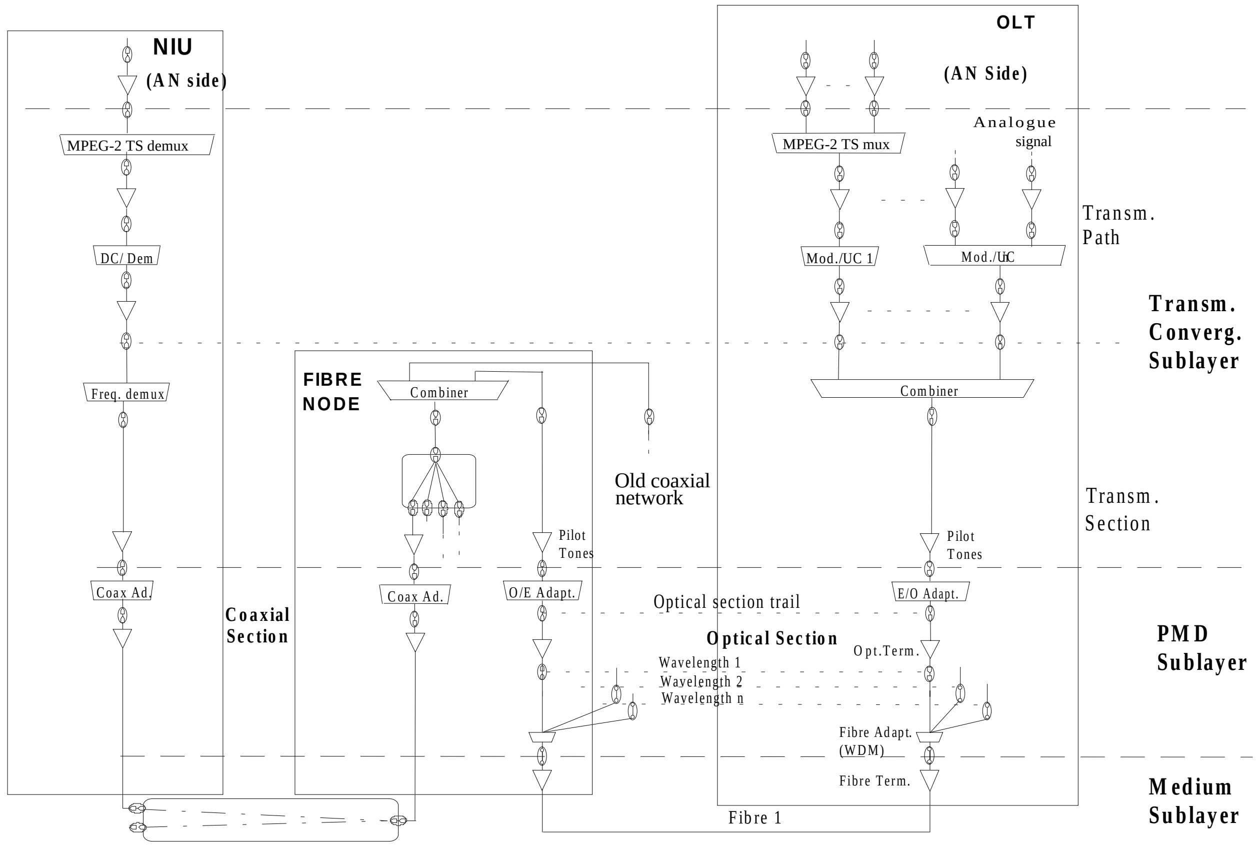


Figure G.4: Functional architecture of an HFC distributive system

G.2.2 HFC MPEG-2 based system

The functional architecture of an HFC MPEG-2 based system is given in figure G.5. Only downstream functions are shown. This differs from the model of a distributive system in subclause G.2.1 in that functions to transport the TDMA protocol control information have been added. As in this previous case, the NT is not shown, as it has to be clarified which functions are pertinent to the NT.

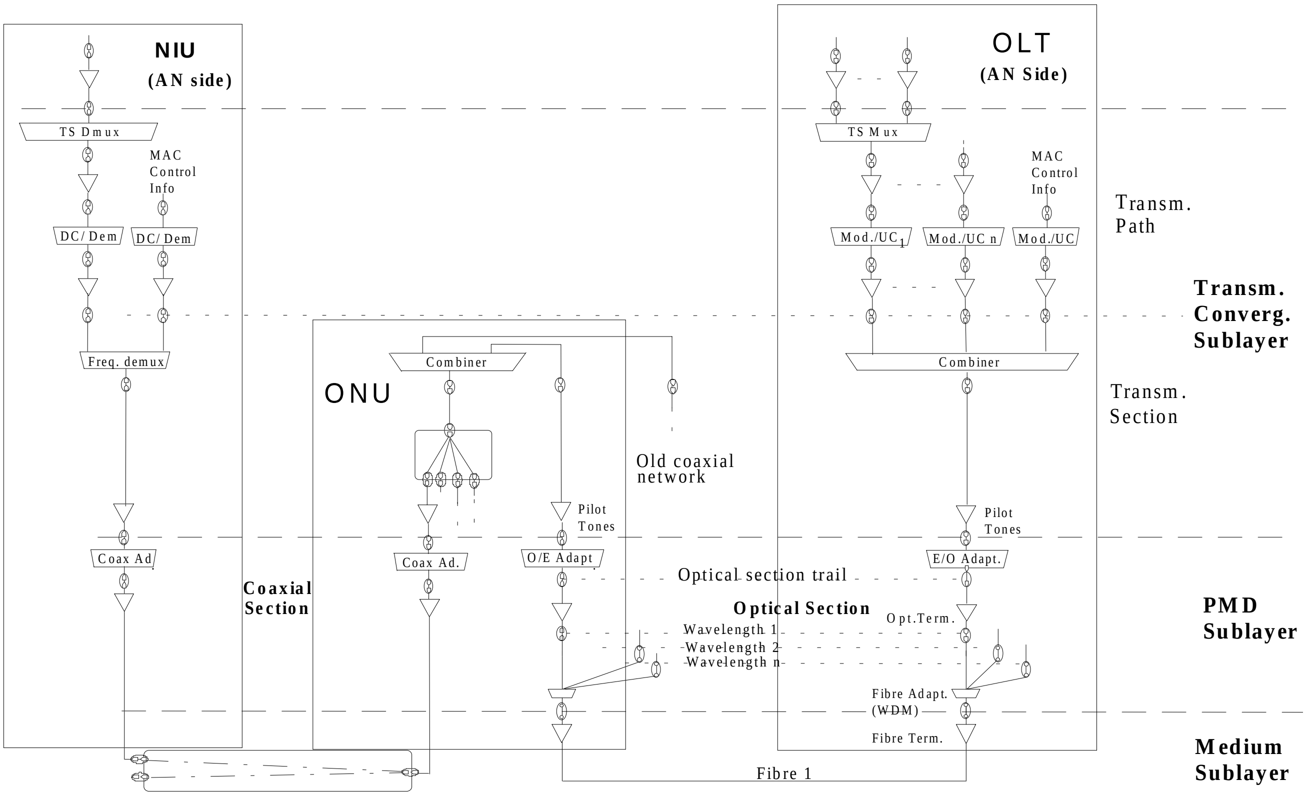


Figure G.5: Functional architecture of an HFC MPEG-2 based system (downstream functions)

G.2.3 HFC ATM based system

Figure G.6 shows the functional model of the AN specific downstream functions of an ATM based HFC system. This differs from the MPEG-2 based HFC system in subclause G.2.2 in that an ATM transport multiplexer has been added at the transmission path level.

Another difference between figure G.5 and figure G.6 is the location of the power splitting function in the fibre node. This does not impact the transport scheme used; rather the distinction is included to illustrate the options available. In figure G.5 each coaxial network has its own amplifier (represented as the coaxial adaptation function), whereas in figure G.6 all coaxial networks supported by the same fibre node are driven by a single amplifier.

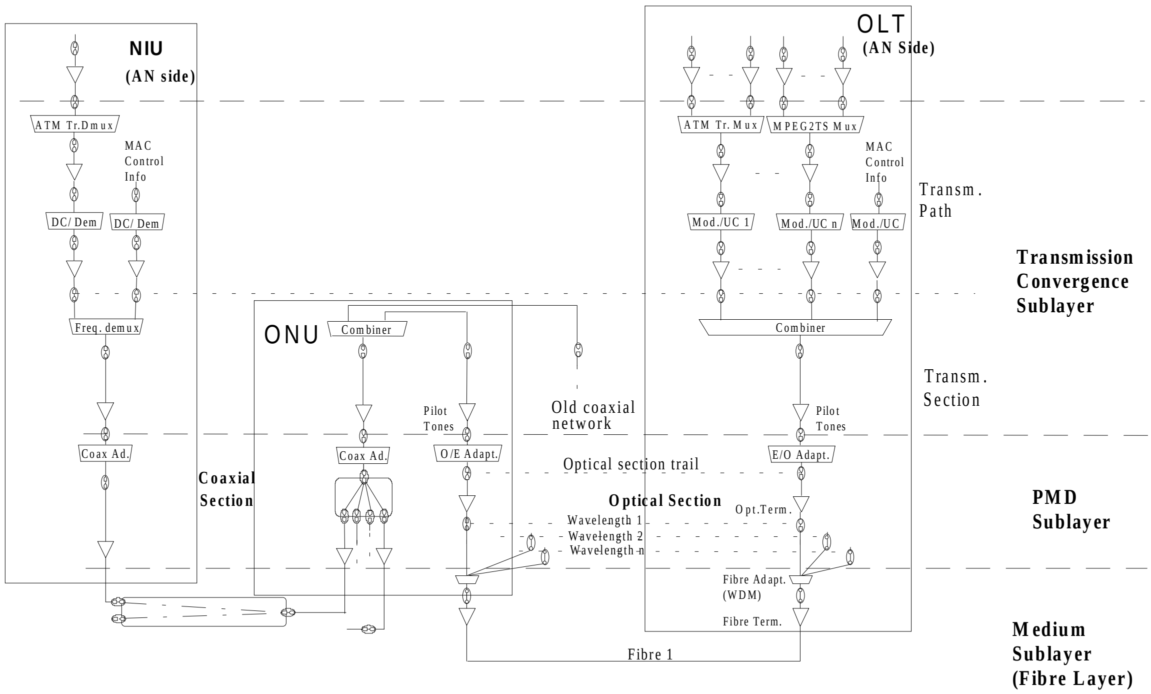


Figure G.6: Functional architecture of an HFC ATM based system (downstream functions)

Annex H (informative): Examples of overlay networks

H.1 HFTP Overlay and integration

A launch concept for HFTP Systems, which could be easily implemented, could begin as a kind of overlay structure, as if bypassing the existing infrastructure. In such an overlay structure (see figure H.1), the fibre optic system would first be set up between the broadband exchange and the distribution area. The copper twin wires of the subscriber line could, if necessary, be looped via the ONU. Then the traditional services could still be carried via the copper main cable as required, and the new services via the optical section of the AN. Because of their particular characteristics, the telephone service and ISDN BA are ideal candidates for such bypassing. On the other hand, accesses with more bandwidth (e.g. ISDN PRA) could be integrated within the broadband data stream of the VDSL system.

However, it is also possible to transmit narrowband services integrated up to the ONU, in order then to transport them on the copper drop together with broadband services. It is equally possible to implement the so-called User Port Function for these services first at the network termination. However, in this case the problems of remote powering and power consumption are to be expected.

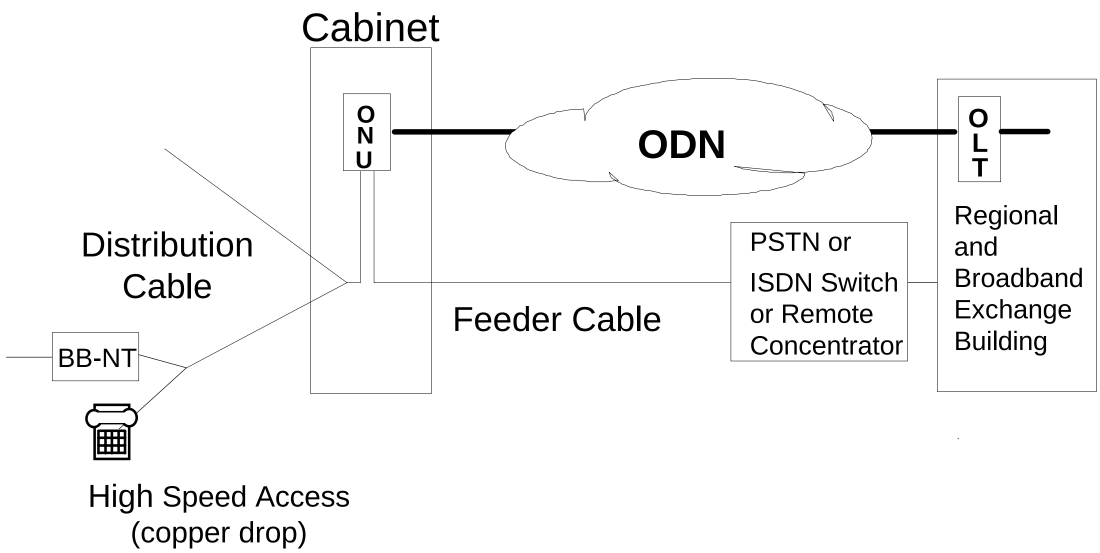


Figure H.1: HFTP overlay

H.2 Overlay HFC (passband system based) and FTTB/C (baseband system based) networks

In the case of an existing HFC network for analogue broadcast services, it is possible to overlay it with an FTTC/B network in order to provide additional digital interactive services while sustaining the previous capital investment for the HFC network.

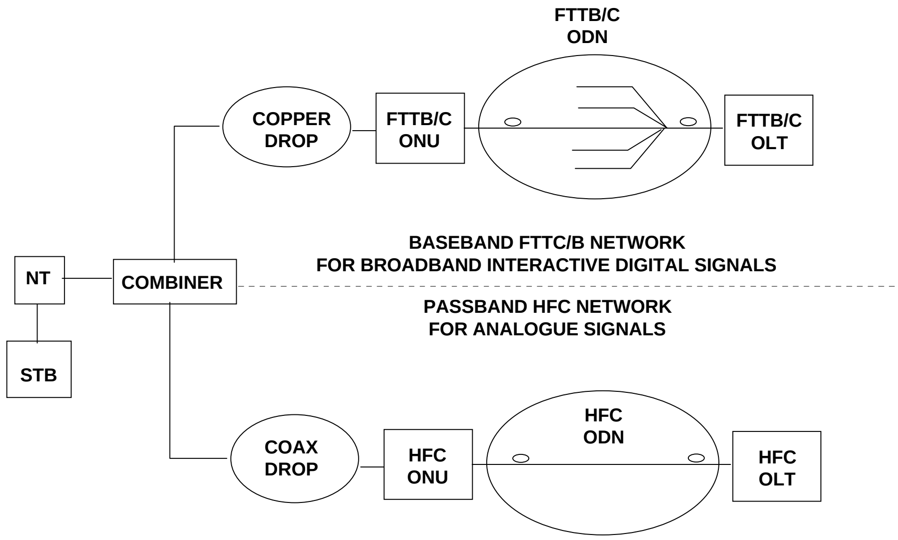


Figure H.2: Overlay of FTTB/C and HFC networks

The integration of the services may be done in a multiplexing point (combiner). At this point, different signals coming from different media/systems are multiplexed onto a single medium to carry different services to the users in an integrated way (in a passive or active way). This is shown in figure H.2.

Where HFC and FTTB/C are overlaid, it may be possible to multiplex analogue signals coming from a passband HFC network and broadband digital signals coming from a baseband FTTB/C network into the same coax cable toward the user using FDM. In this case the "combiner" function could be located at any place in the drop segment between the ONU and the NT functional blocks.

This solution permits the integration of analogue CATV signals and broadband interactive digital signals into the same medium.

ONU powering can be delivered on the same coax feeder cable used to carry the RF signal. This could also be useful to overcome regulatory constraints. An example is shown in figure H.3.

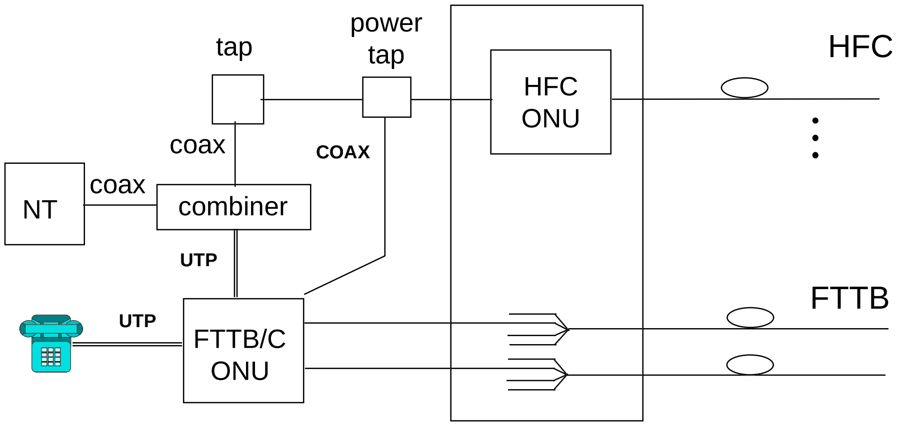


Figure H.3: Powering of FTTB/C ONU from coax feeder

Bibliography

DEN/TMN-00003: "V interfaces at the digital Service Node (SN); Management interfaces associated with the VB5.2 reference point; Part 1: Interface specification".

History

Document history		
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