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SERIES G: TRANSMISSION SYSTEMS AND MEDIA, DIGITAL SYSTEMS AND NETWORKS

Digital sections and digital line system – Optical line systems for local and access networks

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Broadband optical access systems based on Passive Optical Networks (PON)

ITU-T Recommendation G.983.1

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ITU-T Recommendation G.983.1

Broadband optical access systems based on Passive Optical Networks (PON)

Summary

This Recommendation describes a flexible optical fibre access network capable of supporting the bandwidth requirements of narrowband and broadband services. This Recommendation describes systems with nominal downstream line rates of 155.52, 622.08 and 1244.16 Mbit/s, and nominal upstream line rates of 155.52 and 622.08 Mbit/s. Both symmetrical and asymmetrical systems are described. This Recommendation proposes the physical layer requirements and specifications for the physical media dependent layer, the TC layer and the ranging protocol of an ATM-based Broadband Passive Optical Network (B-PON). This revised version of G.983.1 incorporates the material from: G.983.1 (1998), G.983.1 Cor.1 (1999), G.983.1 Amd.1 (2001), G.983.1 Cor.1 Erratum 1 (2002), G.983.1 Amd.2 (2003), G.983.1 Implementor's Guide (2003).

Source

ITU-T Recommendation G.983.1 was approved on 13 January 2005 by ITU-T Study Group 15 (2005-2008) under the ITU-T Recommendation A.8 procedure.

FOREWORD

The International Telecommunication Union (ITU) is the United Nations specialized agency in the field of telecommunications. The ITU Telecommunication Standardization Sector (ITU-T) is a permanent organ of ITU. ITU-T is responsible for studying technical, operating and tariff questions and issuing Recommendations on them with a view to standardizing telecommunications on a worldwide basis.

The World Telecommunication Standardization Assembly (WTSA), which meets every four years, establishes the topics for study by the ITU-T study groups which, in turn, produce Recommendations on these topics.

The approval of ITU-T Recommendations is covered by the procedure laid down in WTSA Resolution 1.

In some areas of information technology which fall within ITU-T's purview, the necessary standards are prepared on a collaborative basis with ISO and IEC.

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ITU-T Recommendation G.983.1

Broadband optical access systems based on Passive Optical Networks (PON)

1 Scope

This Recommendation is intended to describe flexible access networks using optical fibre technology. The focus is primarily on a network to support services with a bandwidth requirement greater than ISDN basic rate; it would include video and distributive services.

This Recommendation describes characteristics of an Optical Access Network (OAN) with the capability of transporting various services between the user-network interface and the Service node interface.

The OAN described in this Recommendation should enable the network operator to provide a flexible upgrade to meet future customer requirements, in particular in the area of the Optical Distribution Network (ODN). The ODN considered is based on point-to-multipoint tree and branch option.

This Recommendation concentrates on the fibre issues; the copper issues of hybrid systems are described elsewhere, e.g., xDSL standardization.

This Recommendation covers issues between the Service node interface and the User network.

Although this Recommendation concentrates on issues relating to ATM over a passive optical network, other solutions are not precluded.

This Recommendation proposes the physical layer requirements and specifications for the physical media dependent layer, the TC layer and the ranging protocol of an ATM-based Broadband Passive Optical Network (B-PON).

This Recommendation is part of the G.983.x series. The other major components of this series include:

- G.983.2 (2002), ONT management and control interface specification for B-PON.
- G.983.3 (2001), A broadband optical access system with increased service capability by wavelength allocation.
- G.983.4 (2001), A broadband optical access system with increased service capability using dynamic bandwidth assignment.
- G.983.5 (2001), A broadband optical access system with enhanced survivability.

2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; all users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

[1] ITU-T Recommendation G.652 (2003), *Characteristics of a single-mode optical fibre cable*.

[2] ITU-T Recommendation G.671 (2005), *Transmission characteristics of optical components and subsystems*.

[3] ITU-T Recommendation G.783 (2004), *Characteristics of synchronous digital hierarchy (SDH) equipment functional blocks*.

[4] ITU-T Recommendation G.902 (1995), *Framework Recommendation on functional access networks (AN) – Architecture and functions, access types, management and service node aspects*.

[5] ITU-T Recommendation G.957 (1999), *Optical interfaces for equipments and systems relating to the synchronous digital hierarchy*.

[6] ITU-T Recommendation G.958 (1994), *Digital line systems based on the synchronous digital hierarchy for use on optical fibre cables*.

[7] ITU-T Recommendation G.982 (1996), *Optical access networks to support services up to the ISDN primary rate or equivalent bit rates*.

[8] ITU-T Recommendation I.321 (1991), *B-ISDN protocol reference model and its application*.

[9] ITU-T Recommendation I.326 (2003), *Functional architecture of transport networks based on ATM*.

[10] ITU-T Recommendation I.356 (2000), *B-ISDN ATM layer cell transfer performance*.

[11] ITU-T Recommendation I.361 (1999), *B-ISDN ATM layer specification*.

[12] ITU-T Recommendation I.432.1 (1999), *B-ISDN user-network interface – Physical layer specification: General characteristics*.

[13] ITU-T Recommendation I.610 (1999), *B-ISDN operation and maintenance principles and functions*.

[14] ITU-T Recommendation I.732 (2000), *Functional characteristics of ATM equipment*.

[15] Federal Information Processing Standard No. 197 (2001), *Advanced Encryption Standard (AES), National Institute of Standards and Technology*.

[16] ITU-T Recommendation G.983.2 (2002), *ONT management and control interface specification for B-PON*.

[17] ITU-T Recommendation G.983.3 (2001), *A broadband optical access system with increased service capability by wavelength allocation*.

[18] ITU-T Recommendation G.983.4 (2001), *A broadband optical access system with increased service capability using dynamic bandwidth assignment*.

[19] ITU-T Recommendation G.983.5 (2002), *A broadband optical access system with enhanced survivability*.

3 Abbreviations

This Recommendation uses the following abbreviations:

AES	Advanced Encryption Standard
AF	Adaptation Function
APS	Automatic Protection Switching
ATM	Asynchronous Transfer Mode
BER	Bit Error Ratio
BIP	Bit Interleaved Parity
B-ISDN	Broadband Integrated Services Digital Network

B-PON	Broadband Passive Optical Network
CID	Consecutive Identical Digit
CPE	Cell Phase Error
CRC	Cyclic Redundancy Check
DSL	Digital Subscriber Line
ECB	Electronic Code Book
E/O	Electrical/Optical
FP-LD	Fabry-Perot Laser Diode
FTTB/C	Fibre to the Building/Curb
FTTCab	Fibre to the Cabinet
FTTH	Fibre to the Home
HEC	Header Error Control
IEC	International Electrotechnical Commission
ISDN	Integrated Services Digital Network
LAN	Local Area Network
LCD	Loss of Cell Delineation
LCF	Laser Control Field
LSB	Least Significant Bit
LT	Line Terminal
MAC	Media Access Control
MLM	Multi-Longitudinal Mode
MSB	Most Significant Bit
NRZ	Non Return to Zero
NT	Network Termination
O/E	Optical/Electrical
OAM	Operations, Administration and Maintenance
OAN	Optical Access Network
ODF	Optical Distribution Frame
ODN	Optical Distribution Network
OLT	Optical Line Termination
OMCC	ONT Management and Control Channel
OMCI	ONT Management and Control Interface
ONT	Optical Network Termination
ONU	Optical Network Unit
OpS	Operations System
ORL	Optical Return Loss
PLOAM	Physical Layer OAM

PON	Passive Optical Network
PRBS	Pseudo-Random Bit Sequence
PST	PON Section Trace
PSTN	Public Switched Telephone Network
QoS	Quality of Service
RAU	Request Access Unit
RMS	Root Mean Square
RXCF	Receiver Control Field
SDH	Synchronous Digital Hierarchy
SLM	Single-Longitudinal Mode
SN	Serial Number
SNI	Service Node Interface
TC	Transmission Convergence
TDMA	Time Division Multiple Access
UI	Unit Interval
UNI	User Network Interface
UPC	Usage Parameter Control
VC	Virtual Channel
VP	Virtual Path
VPI	Virtual Path Identifier
WDM	Wavelength Division Multiplexing

4 Definitions

This Recommendation defines the following terms:

4.0 Broadband PON: A term used to refer to the entire system described by the G.983.x family of ITU-T Recommendations. This includes a wide range of broadband services, and goes beyond ATM access. For this reason, B-PON supersedes the older usage of ATM-PON.

4.1 churning: A function which can be applied to the downstream user data from an OLT to its ONUs. Churning provides the necessary function of data scrambling and offers a low level of protection for data confidentiality. It is installed at the TC layer of the ATM-PON system and can be activated for point-to-point downstream connections.

4.2 diplex working: Bidirectional communication using a different wavelength for each direction of transmission over a single fibre.

4.3 duplex working: Bidirectional communication using the same wavelength for both directions of transmission over a single fibre.

4.4 grant: OLT controls each upstream transmission from ONUs by sending a permission. Grant is a permission to transmit an upstream cell of each ONU when an ONU receives own grant.

4.5 logical reach: Defined as the maximum length that can be achieved for a particular transmission system independent of optical budget.

4.6 mean signal transfer delay: The average upstream and downstream values between reference points "V" and "T", a given value is determined by measuring round-trip delay, then dividing by 2.

4.7 optical access network (OAN): The set of access links sharing the same network-side interfaces and supported by optical access transmission systems. The OAN may include a number of ODNs connected to the same OLT.

4.8 optical distribution network (ODN): An ODN provides the optical transmission means from the OLT towards the users, and vice versa. It utilizes passive optical components.

4.9 optical line termination (OLT): An OLT provides the network-side interface of the OAN, and is connected to one or more ODNs.

4.10 ONT management and control channel (OMCC): The communications circuit connecting the control function of the OLT to that of the ONT. The protocol used for this is defined in ITU-T Rec. G.983.2.

4.11 ONT management and control interface (OMCI): The interface defined in ITU-T Rec. G.983.2 that provides a uniform method for managing faults, configuration, performance, and security on ONTs.

4.12 optical network termination (ONT): An ONU used for FTTH and includes the User Port function. This Recommendation uses the term "ONU" to refer to both ONTs and ONUs. Any reference to ONUs includes ONTs as well within this Recommendation.

4.13 optical network unit (ONU): An ONU provides (directly or remotely) the user-side interface of the OAN, and is connected to the ODN. This Recommendation uses the term "ONU" to refer to both ONTs and ONUs. Any reference to ONUs includes ONTs as well within this Recommendation.

4.14 ranging: It is necessary to transmit an upstream cell without cell collision in this system. Ranging is a function to measure the logical distance between each ONU and OLT and decide the transmission timing when each ONU receives a grant.

4.15 service port function: The Service Port Function (SPF) adapts the requirements defined for a specific SNI to the common bearers handling and selects the relevant information for treatment in the AN system management function.

4.16 time division multiple access (TDMA): Transmission technique involving the multiplexing of many time slots onto the same time payload.

4.17 user port function: The User Port Function (UPF) adapts the specific UNI requirements to the core and management functions. The AN may support a number of different accesses and user network interfaces which require specific functions according to the relevant interface specification and the access bearer capability requirements, i.e., bearers for information transfer and protocols.

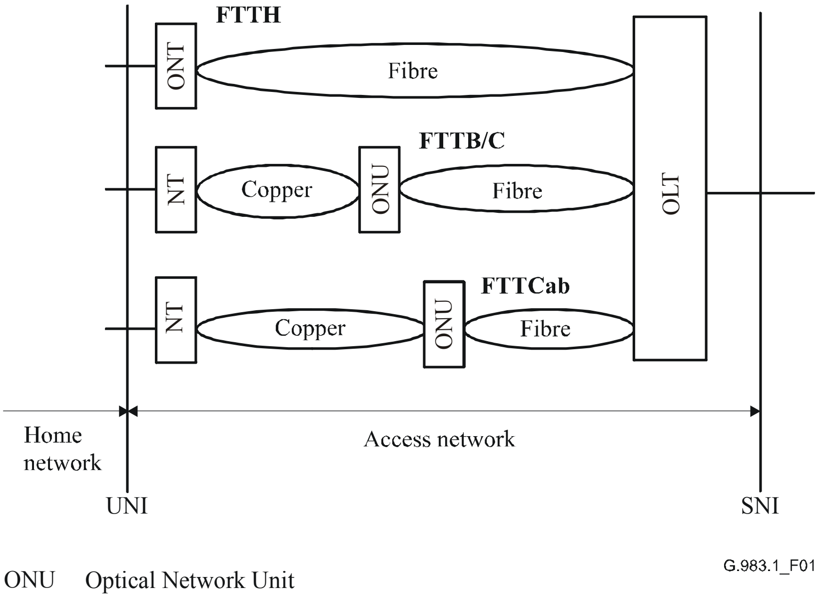
4.18 verification: It is possible for a malicious user to masquerade as other ONU and use the network if the user knows that the ONU is off power. Verification is a function to check whether the connected ONU is masqueraded by a malicious user.

4.19 wavelength division multiplexing (WDM): Bidirectional multiplexing using different optical wavelength for up and downstream signals.

5 Architecture of the optical access network

5.1 Network architecture

The optical section of a local access network system could be either a point-to-point, active, or passive point-to-multipoint architecture. Figure 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 Optical Access Network (OAN) is common to all architectures shown in Figure 1, hence commonality in this system has the potential to generate large world-wide volumes.



ONU Optical Network Unit
ONT Optical Network Termination
OLT Optical Line Termination
NT Network Termination

Figure 1/G.983.1 – Network architecture

The FTTB/C and FTTCab network options are predominantly different only as a result of implementation; therefore, they can be treated similarly in this Recommendation.

5.1.1 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 must be able to provide in a flexible way the narrow-band telephone services with the appropriate timing for the introduction.

5.1.2 FTTH scenario

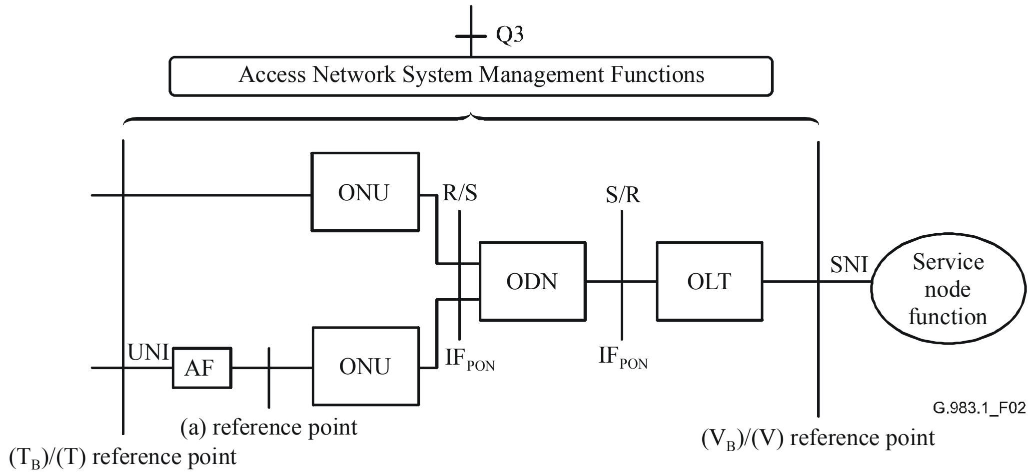
Fibre to the Home (FTTH) service drivers are similar to those of the previous scenarios and are determined by the following:

_ Indoor ONU's can be considered, resulting in more favorable 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 easy, 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 may counterbalance a slightly higher per line cost. In that situation the FTTH scenario may be regarded as economically feasible even in the short term.

5.2 Reference configuration

The reference configuration from ITU-T Rec. G.982 is shown in Figure 2.



ONU	Optical Network Unit
ODN	Optical Distribution Network
OLT	Optical Line Termination
AF	Adaptation Function
S	Point on the optical fibre just after the OLT[Downstream]/ONU[Upstream] optical connection point (i.e., optical connector or optical splice).
R	Point on the optical fibre just before the ONU[Downstream]/OLT[Upstream] optical connection point (i.e., optical connector or optical splice).
(a)	Reference point – This reference point is added to differentiate the AF from the ONU.

Figure 2/G.983.1 – Reference configuration for an ATM based PON

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.

This clause describes the reference architecture for supporting ATM over a PON. This system consists of Optical Line Termination (OLT), Optical Network Unit (ONU) and fibre cable which has a Passive Optical Network (PON) configuration with a passive optical splitter. One fibre is passively split between multiple ONU's who 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 TDMA protocol is required.

5.2.1 Service Node Interface

See ITU-T Rec. G.902.

5.2.2 Interface at the reference points S/R and R/S

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

5.3 Functional blocks

5.3.1 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. The ONU and OLT provide transparent ATM transport service between the UNIs and the SNI over the PON.

5.3.2 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 IFPON are described as consisting of Physical Media 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 Rec. I.732.

The Physical Media Dependent layer would include the modulation schemes for both the upstream and downstream channels (they may be different). It may be possible for the specification to allow for more than one type of Physical Media 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 performed at the ATM layer at both an OLT and ONU would include cell relaying.

5.3.3 Optical Distribution Network

The Optical Distribution Network provides the optical transmission means from the OLT towards the users and vice versa. It utilizes passive optical components.

5.4 ONU functional block

As an example, the FTTH ONT is active and decouples the access network delivery mechanism from the in-house distribution. The ONT core consists of ODN interface, User Port, Transmission, Services and Customers Multiplexing (MUX)/demultiplexing functions and powering, see Figure 3.

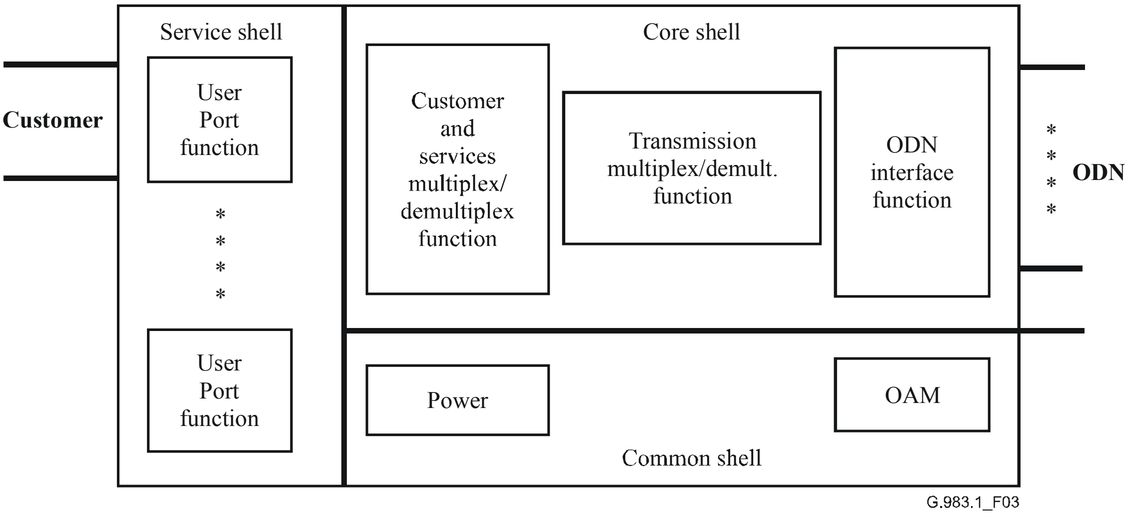


Figure 3/G.983.1 – Example of ONT functional blocks

5.4.1 Optical Distribution Network interface

The ODN interface handles the optoelectronic conversion process. The ODN interface 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.

5.4.2 Multiplexing

Multiplexer (MUX) multiplexes service interfaces to ODN interface. Only valid ATM cells can be passed through the MUX, so many VPs can share the assigned upstream bandwidth effectively.

5.4.3 User Port

The User Port interfaces over UNI to a terminal. The User Port may handle inserting ATM cells into the upstream payload and extracting ATM cells from the downstream payload.

5.4.4 ONU powering

ONU powering may be implementation dependent.

5.5 Optical Line Termination functional block

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

The OLT consists of three parts: the service port function; ODN interface; and MUX for VP grooming (see Figure 4). This combination is not intended to preclude the Virtual Channel (VC) layer function in the OLT. VC layer function is for further study.

1) *Service port function*

   The function interfaces to service nodes. The service port function may handle inserting ATM cells into the upstream SDH payload and extracting ATM cells from the downstream SDH payload. The function may be duplicated, then the protection switching function is necessary.

2) *MUX*

   The MUX provides VP connections between the service port function and the ODN interface and different VPs are assigned to different services at IF_{PON}. Various information such as main contents, signalling, and OAM flows are exchanged by using VCs of the VP.

3) *ODN interface*

The PON Line Terminal handles the optoelectronic conversion process. The ODN interface handles inserting ATM cells into the downstream PON payload and extracting ATM cells from the upstream PON payload.

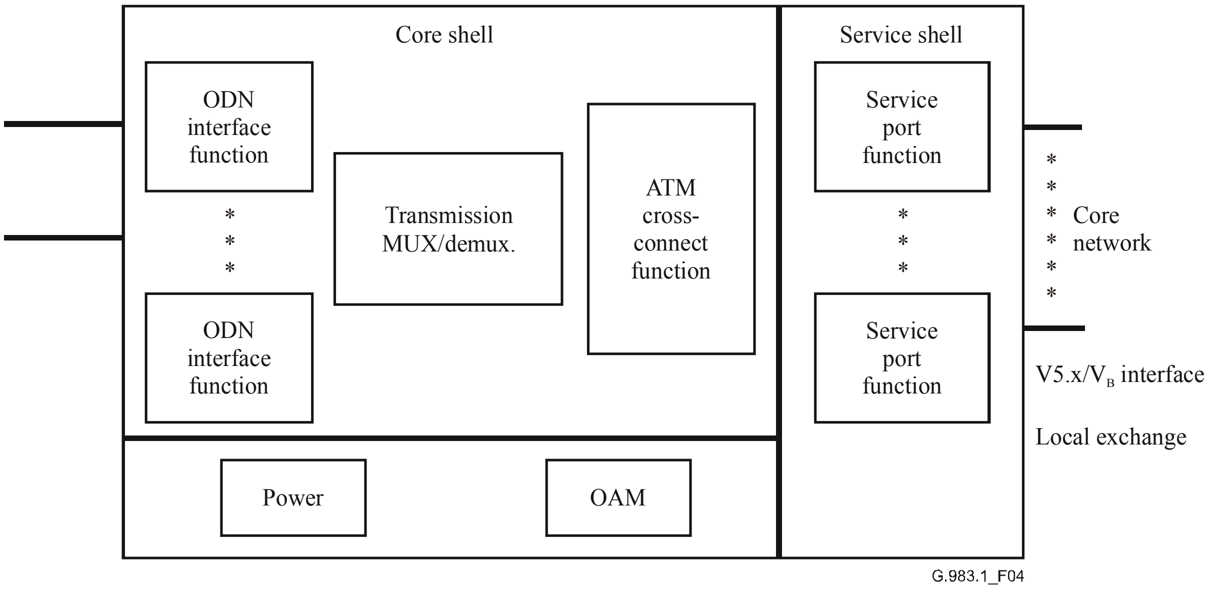


Figure 4/G.983.1 – Example of OLT functional blocks

5.6 Optical Distribution Network functional block

In general, the Optical Distribution Network (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 (see ITU-T Rec. G.982).

5.6.1 Passive optical elements

The ODN consists of passive optical elements:

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

The specific information required to describe passive optical components is described in ITU-T Rec. G.671.

The specific information required to describe optical fibres and cable is described in ITU-T Rec. G.652.

5.6.2 Optical interfaces

In the context of the reference configuration, Figure 5 shows the generic physical configuration of an ODN.

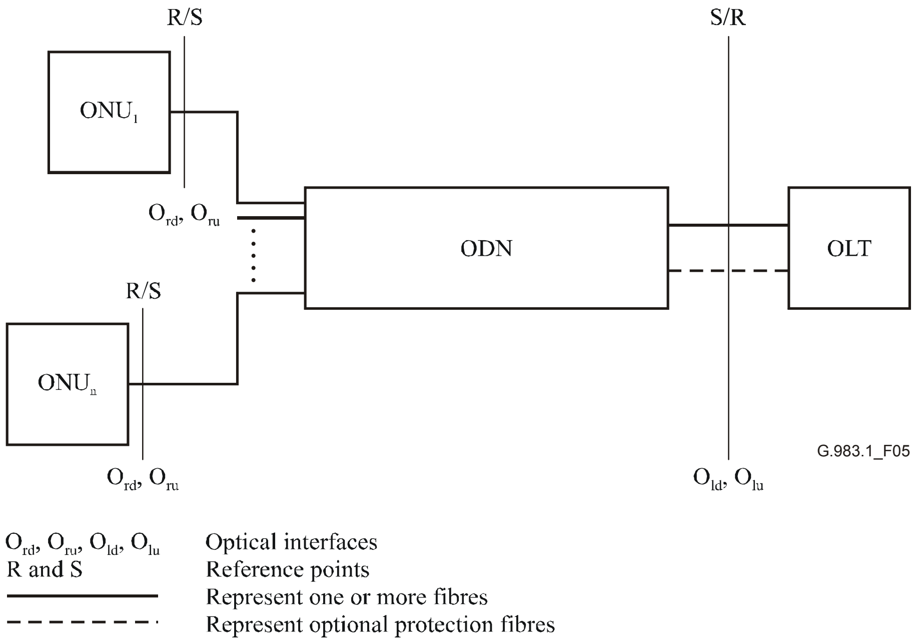


Figure 5/G.983.1 – Generic physical configuration of the Optical Distribution Network

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 path 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 5:

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

– O_{lu}, O_{ld} Optical interfaces at the reference point S/R 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).

Specification of the optical interfaces (O_{ru}, O_{rd}, O_{lu}, O_{ld}) are defined in clause 8.

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 1310 nm and 1550 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 Rec. G.652.

5.6.2.1 Optical Distribution Network model loss calculations

This is described in ITU-T Rec. G.982.

5.6.2.2 Optical Distribution Network model loss calculation technique

This is described in ITU-T Rec. G.982.

6 Services

Such a high-speed access system could provide the complete range of all currently known and new services being discussed for residential subscribers and business customers. Here, transmission system's service independence has to be regarded.

These services cover a broad range of network requirements like bit rate, symmetry/asymmetry or delay, and range from video distribution, with varying degrees of interactivity, to electronic data transfer, LAN interconnection, transparent Virtual Paths, and so on.

What specific services should be provided are more clear to some operators than to others and depend heavily on the particular regulatory conditions of each operator's markets, as well as on the own market's potential. How these services are delivered in a cost-effective way is a function not only of legal conditions, but also of factors including existing telecommunications infrastructure, dwelling distribution and residential and business customers mix.

In spite of this varied market background there are some features which have been perceived as common to all parties. They can be summarized as follows:
– Some services require bit rates higher than those supported by PSTN and basic ISDN. These bit rates are best delivered on fibre based or fibre hybrid networks.
– As the services evolve and newer services are introduced the bandwidth and management requirements will increase. This requires the access network to be flexible and easily upgradable.

7 User Network Interface and Service Node Interface

The location of UNI and SNI is preliminary given in the reference configuration (see Table 1).

Table 1/G.983.1 – UNI and SNI

Service type	UNI standard	SNI standard
Defined in ITU-T Rec. G.982	ITU-T Rec. G.902	ITU-T Rec. G.902
– Digital broadband video system – Multimedia services – VP leased line – ATM SVC	ITU-T Rec. I.432 IEEE 802.3	ITU-T Rec. G.967.1 ITU-T Rec. G.967.2

8 Optical network requirements

8.1 Layered structure of optical network

Layering is based on ITU-T Rec. G.982. The ODN refers to the fibre distribution network based on passive optical splitters, branching components. The OAN is the system between the "V" and "T" reference points (Figure 2). 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 medium, TC, and path layer (see ITU-T Recs G.902, I.326 and G.982). As an example, an ATM-PON is shown in Table 2. In the ATM-PON network, path layer corresponds to the Virtual Path (VP) of the ATM layer.

Table 2/G.983.1 – Layered structure of ATM-PON network

<table>
<tr><th colspan="3">Path layer</th><th>Refer to ITU-T Rec. I.732</th></tr>
<tr><td rowspan="3">Transmission medium layer
(Note)</td><td rowspan="2">TC layer</td><td>Adaptation</td><td>Refer to ITU-T Rec. I.732</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 must provide the related OAM functions.</td></tr>
</table>

The TC layer is divided into PON transmission and adaptation sublayers, which correspond to the Transmission Convergence sublayer of the Broadband Integrated Services Digital Network (B-ISDN) in ITU-T Rec. I.321. 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.

The two layers considered are the physical medium dependent layer and the TC layer, based on G.958 layering principles.

8.2 Physical medium dependent layer requirements for the ATM-PON

8.2.1 Digital signal nominal bit rate

The transmission line rate should be a multiple of 8 kHz. BPON systems will have nominal line rates (downstream/upstream) of:

- 155.52 Mbit/s/155.52 Mbit/s;
- 622.08 Mbit/s/155.52 Mbit/s;
- 622.08 Mbit/s/622.08 Mbit/s;
- 1244.16 Mbit/s/155.52 Mbit/s;
- 1244.16 Mbit/s/622.08 Mbit/s.

Parameters to be defined are categorized by downstream and upstream, and nominal bit rate as shown in Table 3.

Table 3/G.983.1 – Relation between parameter categories and tables

Transmission direction	Nominal bit rate	Table
Downstream	155.52 Mbit/s	Table 4-b (downstream, 155 Mbit/s)
	622.08 Mbit/s	Table 4-c (downstream, 622 Mbit/s)
	1244.16 Mbit/s	Table 4-d (downstream 1244 Mbit/s)
Upstream	155.52 Mbit/s	Table 4-e (upstream, 155 Mbit/s)
	622.08 Mbit/s	Table 4-f (upstream, 622 Mbit/s)

All parameters are specified as follows, and shall be in accordance with Table 4-a (ODN), Table 4-b (downstream, 155 Mbit/s), Table 4-c (downstream, 622 Mbit/s), Table 4-d (downstream, 1244 Mbit/s), Table 4-e (upstream, 155 Mbit/s), Table 4-f (upstream 622 Mbit/s). These tables are designated in Table 4 in this Recommendation if not ambiguous.

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.

Table 4-a/G.983.1 – Physical medium dependant layer parameters of ODN

Items	Unit	Specification
Fibre type	–	ITU-T Rec. G.652
Attenuation range (ITU-T Rec. G.982)	dB	Class A: 5-20 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)
Bidirectional transmission	–	1-fibre WDM or 2-fibre

Table 4-b/G.983.1 – Optical interface parameters of 155 Mbit/s downstream direction

Items	Unit	Single fibre		Dual fibre	
		OLT transmitter (optical interface O_{ld})			
Nominal bit rate	Mbit/s	155.52		155.52	
Operating wavelength	nm	1480-1580		1260-1360	
Line code	–	Scrambled NRZ		Scrambled NRZ	
Mask of the transmitter eye diagram	–	Figure 6		Figure 6	
Maximum reflectance of equipment, measured at transmitter wavelength	dB	NA		NA	
Minimum ORL of ODN at O_{ld} and O_{lu} (Notes 1 and 2)	dB	more than 32		more than 32	
ODN class		Class B	Class C	Class B	Class C
Mean launched power MIN	dBm	–4	–2	–4	–2
Mean launched power MAX	dBm	+2	+4	+1	+3
Launched optical power without input to the transmitter	dBm	NA		NA	
Extinction ratio	dB	more than 10		more than 10	
Transmitter tolerance to incident light power	dB	more than –15		more than –15	
If MLM Laser – Maximum RMS width	nm	1.8		5.8	
If SLM Laser – Maximum –20 dB width (Note 3)	nm	1		1	
If SLM Laser – Minimum side mode suppression ratio	dB	30		30	
		ONU receiver (optical interface O_{rd})			
Maximum reflectance of equipment, measured at receiver wavelength	dB	less than –20		less than –20	
Bit error ratio	–	less than 10^{-10}		less than 10^{-10}	
ODN class		Class B	Class C	Class B	Class C
Minimum sensitivity	dBm	–30	–33	–30	–33
Minimum overload	dBm	–8	–11	–9	–12
Consecutive identical digit immunity	bit	more than 72		more than 72	
Jitter tolerance	–	Figure 9		Figure 9	
Tolerance to the reflected optical power	dB	less than 10		less than 10	

NOTE 1 – The value of "minimum ORL of ODN at point O_{ru} and O_{rd}, and O_{lu} and O_{ld}" should be more than 20 dB in optional cases which are described in Appendix I.

NOTE 2 – The values on ONU transmitter reflectance for the case that the value of "minimum ORL of ODN at point O_{ru} and O_{rd}, and O_{lu} and O_{ld}" is 20 dB are described in Appendix II.

NOTE 3 – Values of maximum –20 dB width, and minimum side mode suppression ratio are referred to in ITU-T Rec. G.957.

Table 4-c/G.983.1 – Optical interface parameters of 622 Mbit/s downstream direction

Items	Unit	Single fibre			Dual fibre		
		OLT transmitter (optical interface O_{ld})					
Nominal bit rate	Mbit/s	622.08			622.08		
Operating wavelength	nm	1480-1580			1260-1360		
Line code	–	Scrambled NRZ			Scrambled NRZ		
Mask of the transmitter eye diagram	–	Figure 6			Figure 6		
Maximum reflectance of equipment, measured at transmitter wavelength	dB	NA			NA		
Minimum ORL of ODN at O_{lu} and O_{ld} (Notes 1 and 2)	dB	more than 32			more than 32		
ODN class		Class A	Class B	Class C	Class A	Class B	Class C
Mean launched power MIN	dBm	–7	–2	–2	–7	–2	–2
Mean launched power MAX	dBm	–1	+4	+4	–2	+3	+3
Launched optical power without input to the transmitter	dBm	NA			NA		
Extinction ratio	dB	more than 10			more than 10		
Transmitter tolerance to incident light power	dB	more than –15			more than –15		
If MLM Laser – Maximum RMS width	nm	NA			1.4		
If SLM Laser – Maximum –20 dB width (Note 3)	nm	1			1		
If SLM Laser – Minimum side mode suppression ratio	dB	30			30		
		ONU receiver (optical interface O_{rd})					
Maximum reflectance of equipment, measured at receiver wavelength	dB	less than –20			less than –20		
Bit error ratio	–	less than 10^{-10}			less than 10^{-10}		
ODN class		Class A	Class B	Class C	Class A	Class B	Class C
Minimum sensitivity	dBm	–28	–28	–33	–28	–28	–33
Minimum overload	dBm	–6	–6	–11	–7	–7	–12
Consecutive identical digit immunity	bit	more than 72			more than 72		
Jitter tolerance	–	Figure 9			Figure 9		
Tolerance to the reflected optical power	dB	less than 10			less than 10		

NOTE 1 – The value of "minimum ORL of ODN at point O_{ru} and O_{rd}, and O_{lu} and O_{ld}" should be more than 20 dB in optional cases which are described in Appendix I.

NOTE 2 – The values on ONU transmitter reflectance for the case that the value of "minimum ORL of ODN at point O_{ru} and O_{rd}, and O_{lu} and O_{ld}" is 20 dB are described in Appendix II.

NOTE 3 – Values of maximum –20 dB width, and minimum side mode suppression ratio are referred to in ITU-T Rec. G.957.

Table 4-d/G.983.1 – Optical interface parameters of 1244.16 Mbit/s downstream direction

Items	Unit	Single fibre			Dual fibre		
		OLT transmitter (optical interface O_{ld})					
Nominal bit rate	Mbit/s	1244.16			1244.16		
Operating wavelength	nm	1480-1500			1260-1360		
Line code	–	Scrambled NRZ			Scrambled NRZ		
Mask of the transmitter eye diagram	–	Figure 6			Figure 6		
Maximum reflectance of equipment, measured at transmitter wavelength	dB	NA			NA		
Minimum ORL of ODN at O_{lu} and O_{ld} (Notes 1 and 2)	dB	more than 32			more than 32		
ODN class		Class A	Class B	Class C	Class A	Class B	Class C
Mean launched power MIN	dBm	–4	+1	+5	–4	+1	+5
Mean launched power MAX	dBm	+1	+6	+9	+1	+6	+9
Launched optical power without input to the transmitter	dBm	NA			NA		
Extinction ratio	dB	more than 10			more than 10		
Transmitter tolerance to incident light power	dB	more than –15			more than –15		
If MLM Laser – Max. RMS width	nm	NA			NA		
If SLM Laser – Max. –20 dB width (Note 3)	nm	1			1		
If SLM Laser – Minimum side mode suppression ratio	dB	30			30		
		ONU receiver (optical interface O_{rd})					
Maximum reflectance of equipment, measured at receiver wavelength	dB	less than –20			less than –20		
Bit error ratio	–	less than 10^{-10}			less than 10^{-10}		
ODN class		Class A	Class B	Class C	Class A	Class B	Class C
Minimum sensitivity	dBm	–25	–25	–26	–25	–25	–25
Minimum overload (Note 4)	dBm	–4	–4	–4	–4	–4	–4
Consecutive identical digit immunity	bit	more than 72			more than 72		
Jitter tolerance	–	Figure 9			Figure 9		
Tolerance to the reflected optical power	dB	less than 10			less than 10		

NOTE 1 – The value of "minimum ORL of ODN at point O_{ru} and O_{rd}, and O_{lu} and O_{ld}" should be more than 20 dB in optional cases which are described in Appendix I.

NOTE 2 – The values on ONU transmitter reflectance for the case that the value of "minimum ORL of ODN at point O_{ru} and O_{rd}, and O_{lu} and O_{ld}" is 20 dB are described in Appendix II.

NOTE 3 – Values of maximum –20 dB width, and minimum side mode suppression ratio are referred to in ITU-T Rec. G.957.

NOTE 4 – While only –6 dBm overload is required to support the class C ODN, a –4 dBm overload value has been chosen here for ONU receiver uniformity across all ODN classes.

Table 4-e/G.983.1 – Optical interface parameters of 155 Mbit/s upstream direction

Items	Unit	Single fibre		Dual fibre	
		ONU transmitter (optical interface O_{ru})			
Nominal bit rate	Mbit/s	155.52		155.52	
Operating wavelength	nm	1260-1360		1260-1360	
Line code	–	Scrambled NRZ		Scrambled NRZ	
Mask of the transmitter eye diagram	–	Figure 7		Figure 7	
Maximum reflectance of equipment, measured at transmitter wavelength	dB	less than –6		less than –6	
Minimum ORL of ODN at O_{ru} and O_{rd} (Notes 1 and 2)	dB	more than 32		more than 32	
ODN class		Class B	Class C	Class B	Class C
Mean launched power MIN	dBm	–4	–2	–4	–2
Mean launched power MAX	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	
Transmitter tolerance to incident light power	dB	more than –15		more than –15	
If MLM Laser – Maximum RMS width	nm	5.8		5.8	
If SLM Laser – Max. –20 dB width (Note 3)	nm	1		1	
If SLM Laser – Minimum side mode suppression ratio	dB	30		30	
Jitter transfer	–	Figure 8		Figure 8	
Jitter generation from 0.5 kHz to 1.3 MHz	UI p-p	0.2		0.2	
		OLT receiver (optical interface O_{lu})			
Maximum reflectance of equipment, measured at receiver wavelength	dB	less than –20		less than –20	
Bit error ratio	–	less than 10^{-10}		less than 10^{-10}	
ODN class		Class B	Class C	Class B	Class C
Minimum sensitivity	dBm	–30	–33	–30	–33
Minimum overload	dBm	–8	–11	–9	–12
Consecutive identical digit immunity	bit	more than 72		more than 72	
Jitter tolerance	–	NA		NA	
Tolerance to the reflected optical power	dB	less than 10		less than 10	

NOTE 1 – The value of "minimum ORL of ODN at point O_{ru} and O_{rd}, and O_{lu} and O_{ld}" should be more than 20 dB in optional cases which are described in Appendix I.

NOTE 2 – The values of ONU transmitter reflectance for the case that the value of "minimum ORL of ODN at point O_{ru} and O_{rd}, and O_{lu} and O_{ld}" is 20 dB are described in Appendix II.

NOTE 3 – Values of maximum –20 dB width, and minimum side mode suppression ratio are referred to in ITU-T Rec. G.957.

Table 4-f/G.983.1 – Optical interface parameters of 622 Mbit/s upstream direction

Items	Unit	Specifications		
		ONU transmitter (optical interface O_{ru})		
Nominal bit rate	Mbit/s	622.08		
Operating wavelength (Note 3)	nm	MLM type 1 or SLM: 1260-1360 MLM type 2: 1280-1350 MLM type 3: 1288-1338		
Line code	–	Scrambled NRZ		
Mask of the transmitter eye diagram	–	Figure 7		
Maximum reflectance of equipment, measured at transmitter wavelength	dB	less than −6		
Maximum ORL of ODN at O_{ld} and O_{lu} (Notes 1 and 2)	dB	more than 32		
ODN class (Note 5)		Class A	Class B	Class C
Mean launched power MIN	dBm	–6	–1	–1
Mean launched power MAX	dBm	–1	+4	+4
Launched optical power without input to the transmitter	dBm	less than Min sensitivity –10		
Extinction ratio	dB	more than 10		
Transmitter tolerance to incident light power	dB	more than −15		
If MLM laser – Maximum RMS width (Note 3)	nm	MLM type 1: 1.4 MLM type 2: 2.1 MLM type 3: 2.7		
If SLM laser – Max. –20 dB width (Note 4)	nm	1		
If SLM laser – Min. side mode suppression ratio	dB	30		
Jitter transfer	–	Figure 8		
Jitter generation from 2.0 kHz to 5.0 MHz	UI p-p	0.2		
		OLT receiver (optical interface O_{lu})		
Maximum reflectance of equipment, measured at receiver wavelength	dB	less than –20		
Bit error ratio	–	less than 10^{-10}		
ODN class (Note 5)		Class A	Class B	Class C
Minimum sensitivity	dBm	–27	–27	–32
Minimum overload	dBm	–6	–6	–11
Consecutive identical digit immunity	bits	more than 72		
Jitter tolerance	–	NA		
Tolerance to the reflected optical power	dB	less than 10		

Table 4-f/G.983.1 – Optical interface parameters of 622 Mbit/s upstream direction

NOTE 1 – The value of "ORL of ODN at point O_{ru} and O_{rd}, and O_{lu} and O_{ld} MIN" should be more than 20 dB in optional cases that are described in Appendix I.
NOTE 2 – The values of ONU transmitter reflectance for the case that the value of "ORL of ODN at point O_{ru} and O_{rd}, and O_{lu} and O_{ld} MIN" is 20 dB are described in Appendix II.
NOTE 3 – Transmitter types meeting narrower spectral width specifications are allowed wider central wavelength ranges. The specified laser types produce less than 1 dB of optical path penalty over the ODN. Lasers with different optical parameters may be substituted provided that (1) the total wavelength range does not exceed 1260 nm to 1360 nm, and (2) any increase in optical path penalty over 1 dB is compensated by an increase of the minimum transmitted launch power or a decrease of the minimum receiver sensitivity. For interoperability, the specified laser types with less than 1 dB optical path penalty are recommended.
NOTE 4 – Values of –20 dB max width and minimum side mode suppression ratio are referred to in ITU-T Rec. G.957.
NOTE 5 – The values proposed for the upstream Class C are best estimates. They are therefore subject to change in the future.

8.2.2 Physical media and transmission method

8.2.2.1 Transmission medium

This specification is based on the fibre described in ITU-T Rec. G.652.

8.2.2.2 Transmission direction

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

8.2.2.3 Transmission methodology

Bidirectional transmission is accomplished by use of either Wavelength Division Multiplexing (WDM) technique of 1310 nm region and 1550 nm region wavelengths on a single fibre, or unidirectional two fibres of 1310 nm region wavelength.

8.2.3 Bit rate

8.2.3.1 Downstream

The nominal bit rate of the OLT-to-ONU signal is 155.52, 622.08, or 1244.16 Mbit/s. When the OLT and the end office are in their normal operating state, this rate is traceable to a Stratum-1 clock (accuracy of 1×10^{-11}). When the end office is in its free-running mode, the rate of the downstream signal is traceable to a Stratum-3 clock (accuracy of 4.6×10^{-6}). When the OLT is in its free-running mode, the accuracy of the downstream signal is that of a Stratum-4 clock (3.2×10^{-5}).

8.2.3.2 Upstream

When in one of its operating states and given a grant, the ONU shall transmit a signal at 155.52 Mbit/s or 622.08 Mbit/s with an accuracy equal to that of the received downstream signal. The ONU shall not transmit any signal when not in one of its operating states or when not given a grant.

8.2.4 Line code

8.2.4.1 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.

8.2.4.2 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.

8.2.5 Operating wavelength

8.2.5.1 Downstream direction

The operating wavelength range for the downstream direction on single fibre systems shall be 1480-1580 nm. Please note that ITU-T Rec. G.983.3 describes a more comprehensive wavelength plan that narrows this downstream range for single-fibre systems.

The operating wavelength range for the downstream direction on two fibre systems shall be 1260-1360 nm.

8.2.5.2 Upstream direction

The operating wavelength range for the upstream direction shall be 1260-1360 nm.

8.2.6 Transmitter at O_{ld} and O_{ru}

All parameters are specified as follows, and shall be in accordance with Table 4.

8.2.6.1 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 Recommendation indicates a nominal source type. It is understood that the indication of a nominal source type in this Recommendation 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.

8.2.6.2 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.

8.2.6.3 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 in states O6, O7 and O8. and the higher one is the power which shall never be exceeded in states O6, O7 and O8. In ranging mode, state O4 (only for the optical power start-up), the power may go below the specified minimum launched power, and it cannot exceed the specified maximum launched power with more than 3 dB.

NOTE – For the accuracy of measurement, special care for the way of burst signal output from ONU is necessary.

8.2.6.3.1 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 must be less than 0.1 of the one level.

8.2.6.4 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 to from the first bit of the preamble to the last bit of the burst signal inclusive. This does not apply to the optical power set-up procedure (refer to 8.4.4.2 "Ranging procedure in the ONU").

8.2.6.5 Maximum reflectance of equipment, measured at transmitter wavelength

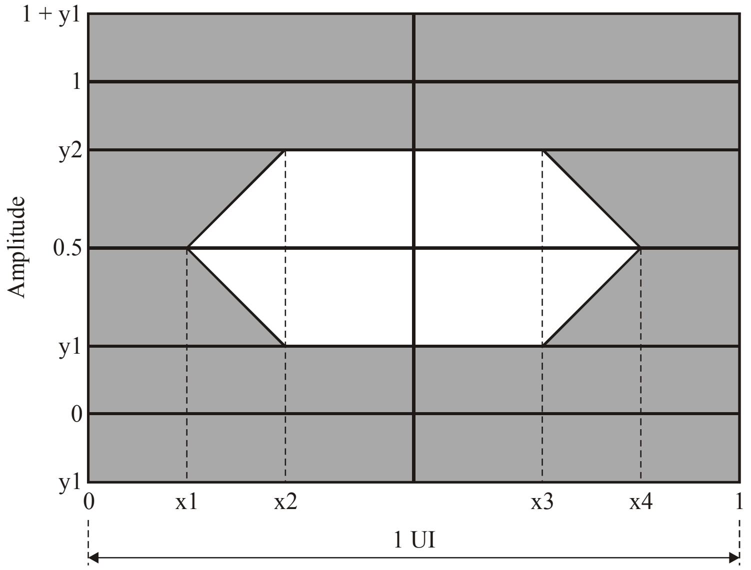
Reflections from equipment (ONU/OLT) back to the cable plant are specified by the maximum permissible reflectance of equipment measured at O_{ld}/O_{ru}. It shall be in accordance with Table 4.

8.2.6.6 Mask of transmitter eye diagram

In this Recommendation, 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.

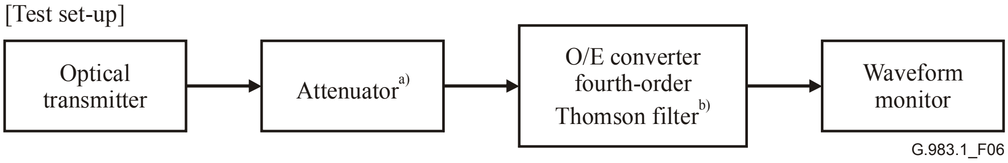
8.2.6.6.1 OLT transmitter

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



	155.52 Mbit/s	622.08 Mbit/s	1244.16 Mbit/s
x1/x4	0.15/0.85	0.25/0.75	0.28/0.72
x1/x4	0.35/0.65	0.40/0.60	0.40/0.60
x1/x4	0.20/0.80	0.20/0.80	0.20/0.80

[Test set-up]



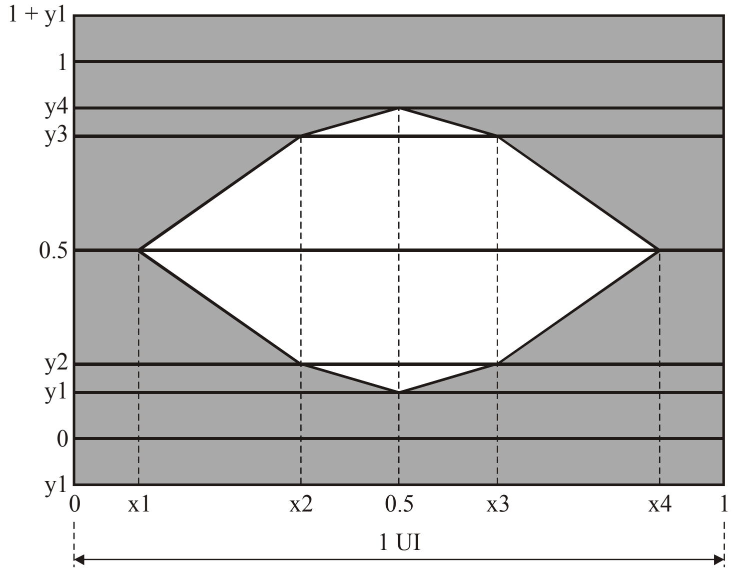
a) Attenuator is used if necessary.

b) Cut-off frequency (3 dB attenuation frequency) of the filter is 0.75 times output nominal bit rate.

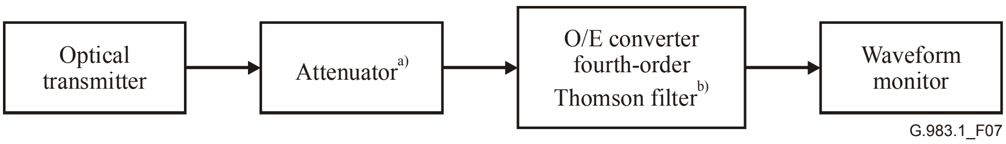
Figure 6/G.983.1 – Mask of the eye diagram for the downstream transmission signal

8.2.6.6.2 ONU transmitter

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



	155.52 Mbit/s	622.08 Mbit/s
x1/x4	0.10/0.90	0.20/0.80
x2/x3	0.35/0.65	0.40/0.60
y1/y4	0.13/0.87	0.15/0.85
y2/y3	0.20/0.80	0.20/0.80



a) Attenuator is used if necessary.

b) Cut-off frequency (3 dB attenuation frequency) of the filter is 0.75 times output nominal bit rate.

Figure 7/G.983.1 – Mask of the eye diagram for the upstream transmission signal

The mask of the eye diagram for the upstream direction burst mode signal is applied to from the first bit of the preamble to the last bit of the burst signal inclusive. This does not apply to the optical power set-up procedure (refer to 8.4.4.2 "Ranging procedure in the ONU").

8.2.6.7 Tolerance to the reflected optical power

The specified transmitter performance must be met in the presence at S of the optical reflection level specified in Table 4.

8.2.7 Optical path between O_{ld}/O_{ru} and O_{rd}/O_{lu}

8.2.7.1 Attenuation range

Three classes of attenuation ranges are being specified as defined in ITU-T Rec. G.982:

– 5-20 dB: Class A;

– 10-25 dB: Class B;

– 15-30 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.

8.2.7.2 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, minimum ORL specification at point S in the ODN shall be better than 20 dB. Appendix I 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 Optical Distribution Frame (ODF). The maximum reflectance of a single discrete element within ITU-T Rec. G.982 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 −32 dB.

8.2.7.3 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 Rec. G.982.

8.2.7.4 Dispersion

Systems considered limited by dispersion have maximum values of dispersion (ps/nm) specified in Table 4. 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 Table 4 with the entry "NA" (not applicable).

8.2.8 Receiver at O_{rd} and O_{lu}

All parameters are specified as follows, and shall be in accordance with Table 4.

8.2.8.1 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.

8.2.8.2 Minimum overload

Receiver overload is the maximum acceptable value of the received average power at point R for a 10^{-10} BER. The receiver should have a certain robustness against increased optical power level due to start-up or potential collisions during ranging, for which a BER of 10^{-10} is not guaranteed.

8.2.8.3 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.

8.2.8.4 Maximum reflectance of receiver equipment, measured at receiver wavelength

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

8.2.8.5 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.

8.2.8.6 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.

8.2.8.7 Jitter performance

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

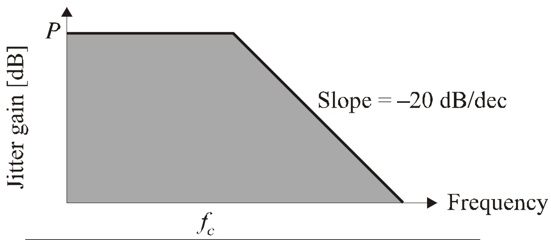
8.2.8.7.1 Jitter transfer

Jitter transfer specification applies only to ONU.

The jitter transfer function is defined as:

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

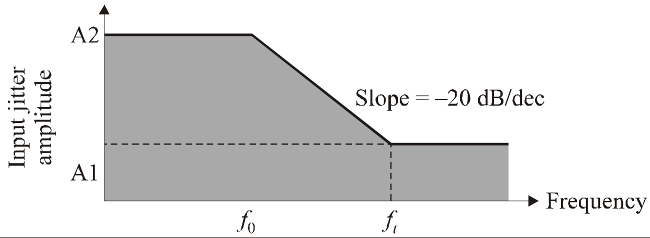
The jitter transfer function of an ONU shall be under the curve given in Figure 8, when input sinusoidal jitter up to the mask level in Figure 9 is applied, with the parameters specified in this figure for each bit rate.



	f_c [kHz]	P [dB]
155.52/155.52	130	0.1
155.52/622.08	500	0.1
155.52/1244.16	1000	0.1
622.08/622.08	500	0.1
622.08/1244.16	1000	0.1

G.983.1_F08

Figure 8/G.983.1 – Jitter transfer for ONU



	f_t [kHz]	f_0 [kHz]	A1 [U1p-p]	A1 [U1p-p]
155.52/155.52	65	6.5	0.075	0.75
155.52/622.08	250	25	0.075	0.75
155.52/1244.16	500	50	0.075	0.75
622.08/622.08	250	25	0.075	0.75
622.08/1244.16	500	50	0.075	0.75

G.983.1_F09

Figure 9/G.983.1 – Jitter tolerance mask for ONU

8.2.8.7.2 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 9, with the parameters specified in that figure for each bit rate.

8.2.8.7.3 Jitter generation

Jitter generation specification applies only to ONU.

An ONU shall not generate more than 0.2 UI peak-to-peak jitter, with no jitter applied to the downstream input. The measurement bandwidth for the 155.52-Mbit/s upstream direction has a range from 0.5 kHz to 1.3 MHz. The measurement bandwidth for the 622.08-Mbit/s upstream direction has a range from 2.0 kHz to 5.0 MHz.

8.2.8.8 Consecutive identical digit (CID) immunity

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

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

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

c) all 0s (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.

8.2.8.9 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.

8.2.8.10 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 Rec. G.957.

8.3 Transmission Convergence layer requirements for the ATM-PON

For an ATM-PON, the following TC layer requirements are described in Table 5.

Table 5/G.983.1 – TC layer requirements

Cell rate decoupling	ITU-T Rec. I.432.1
HEC calculation error correction	ITU-T Rec. I.432.1
Maximum number of virtual paths per PON	4096
Minimum addressing capability	64 ONUs

NOTE – PON addressing can use the full 12-bit VP field of the ATM cell header, as it is used across the VB5 reference point; see Figure 10. The VPI values on the PON do not have to be equal to the VPI values across the VB5 reference point, because the OLT will have a VP cross-connect function. The limit of up to 4096 VPs avoids costly addressing tables in the ONU and enables efficient use of the PON resource.

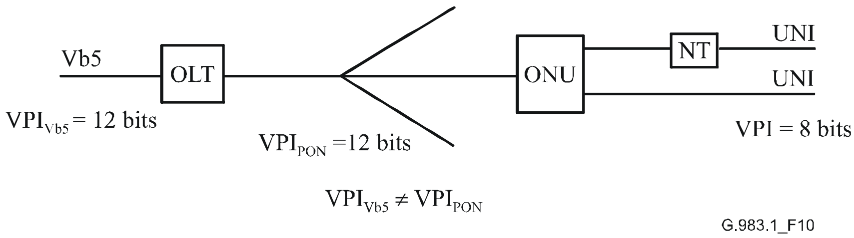


Figure 10/G.983.1 – VP usage on the PON

8.3.1 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.

8.3.2 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.

8.3.3 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 $\left(155.52\times\frac{54}{56}\right)$

The transfer capacity for the 622.08-Mbit/s interface is 599.86 Mbit/s.

The transfer capacity for the 1244.16-Mbit/s interface is 1199.72 Mbit/s.

8.3.4 Upstream interface

The Physical Layer overhead includes the PLOAM cells, the minislots for the MAC channel and the overhead bytes which are added in front of each upstream ATM cell, PLOAM cell or minislot.

The transfer capacities for the upstream interfaces have upper limits of:

– 147.2 Mbit/s $\left(155.52\times\frac{54}{56}\right)$ for the 155.52-Mbit/s interface;

– 588.8 Mbit/s for the 622.08-Mbit/s interface. 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.

8.3.5 Transport-specific TC functions

8.3.5.1 Frame structure

The downstream interface structure for both 155.52 Mbit/s, 622.08 Mbit/s, and 1244.16 Mbit/s consists of a continuous stream of timeslots, each timeslot containing 53 octets of an ATM cell or a PLOAM cell.

Every 28 time slots, a PLOAM cell is inserted. A downstream frame contains two such PLOAM cells and is 56 slots long for the 155-Mbit/s downstream case. For the 622-Mbit/s case, it contains eight PLOAM cells and is 224 slots long. For the 1244-Mbit/s case, it contains sixteen PLOAM cells and is 448 slots long.

In the upstream direction, the frame contains 53 time slots of 56 bytes for the 155-Mbit/s upstream case, and for the 622.08-Mbit/s case, it contains 212 time slots. The OLT request 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.

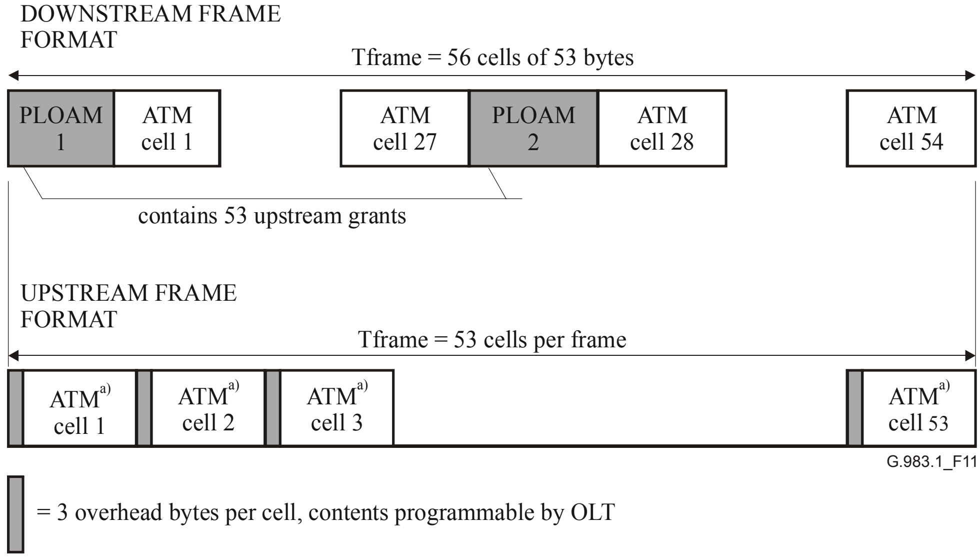
The PLOAM cells are used to convey the Physical Layer OAM information. In addition, they carry the grants used by the ONUs for the upstream access.

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 ONU's queues, in order to implement a dynamic bandwidth allocation. The usage of these divided_slots is optional.

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.

8.3.5.1.1 Frame structure for 155/155-Mbit/s PON

The frame structure for a 155/155-Mbit/s symmetric PON is shown in Figure 11.



[a] Any ATM cell slot can contain an upstream PLOAM or divided slot rate controlled by the OLT.

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

Figure 11/G.983.1 – Frame format for 155.52/155.52-Mbit/s PON

The upstream overhead bytes contain the following fields in Table 6.

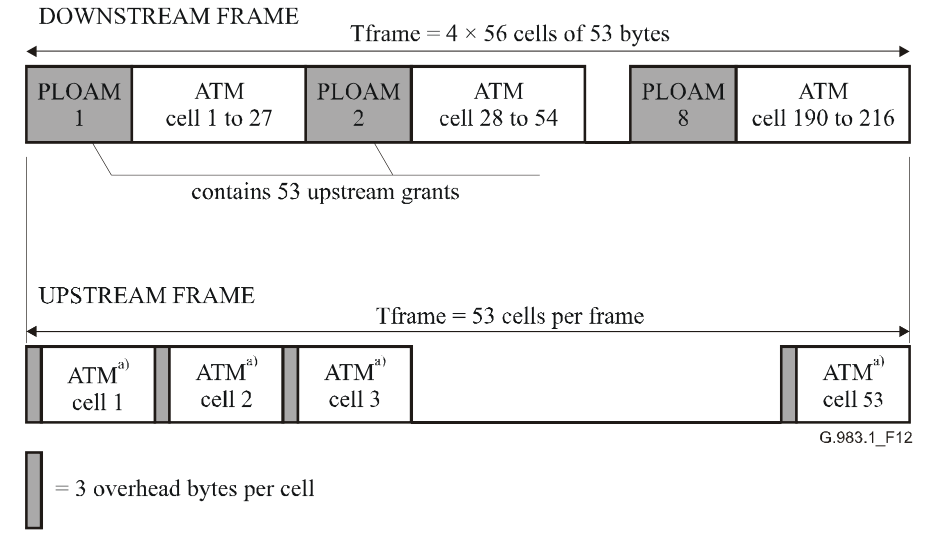
Table 6/G.983.1 – Upstream overhead bytes

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.

8.3.5.1.2 Frame structure for 622/155-Mbit/s PON

In this case the downstream rate is exactly four times higher; this is shown in Figure 12.



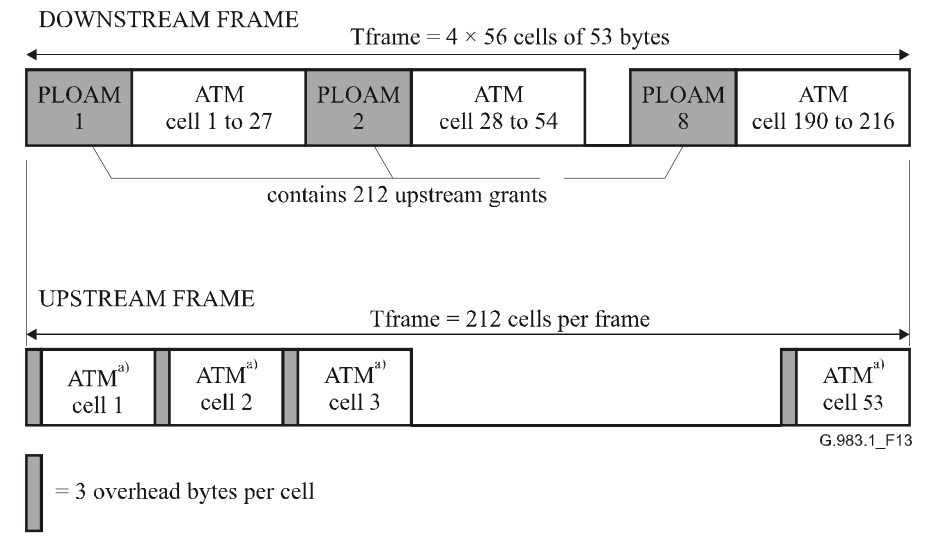
a) Any ATM cell slot can contain an upstream PLOAM or divided slot rate controlled by the OLT.

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

Figure 12/G.983.1 – Frame format for 622.08/155.52 Mbit/s PON

8.3.5.1.3 Frame structure for 622/622-Mbit/s PON

In this case the downstream and upstream rates are both exactly four times higher than the 155-Mbit/s symmetrical case. This is shown in Figure 13.



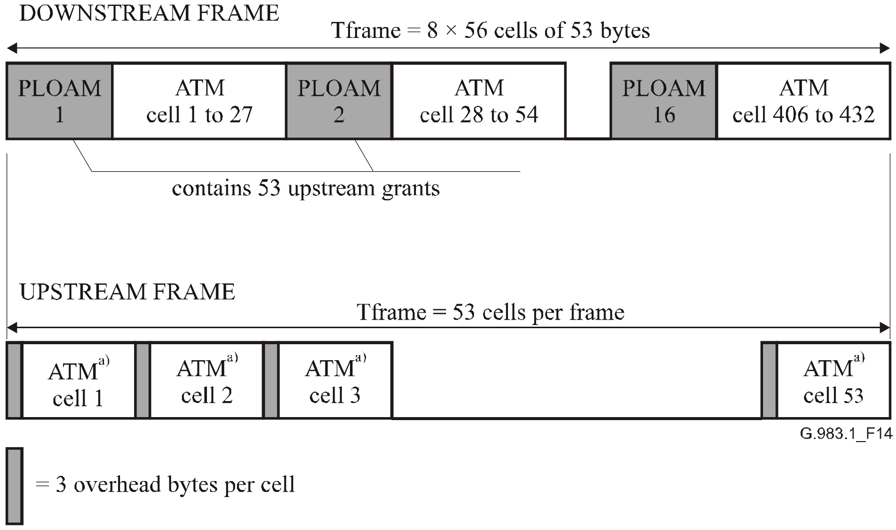
a) Any ATM cell slot can contain an upstream PLOAM or divided slot rate controlled by the OLT.

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

Figure 13/G.983.1 – Frame format for 622.08/622.08-Mbit/s PON

8.3.5.1.4 Frame structure for 1244/155-Mbit/s PON

In this case the downstream rate is exactly eight times higher than the symmetric 155-Mbit/s case. This is shown in Figure 14.



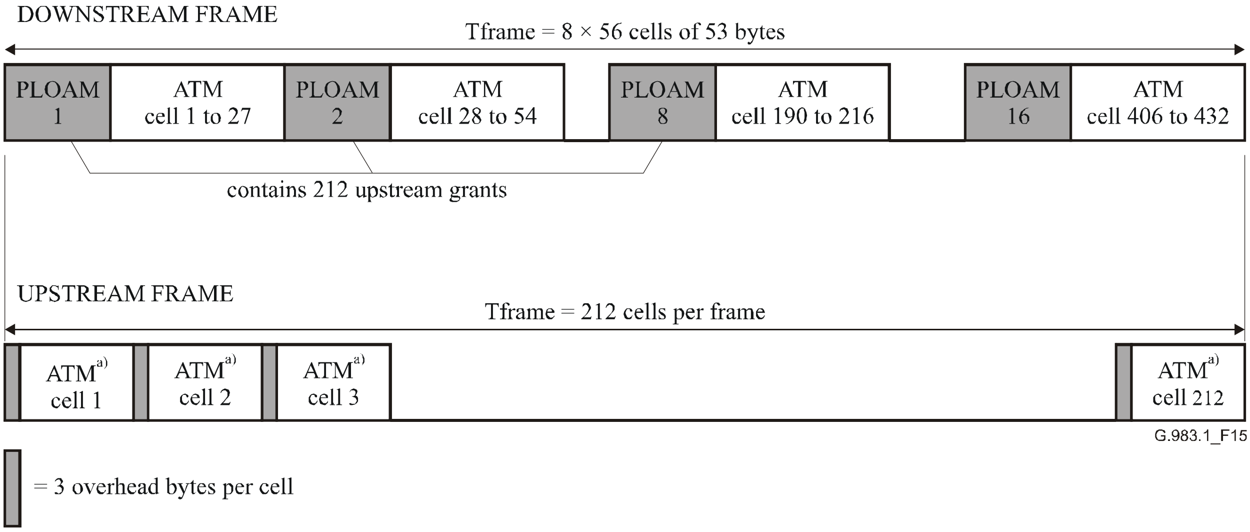
a) Any ATM cell slot can contain an upstream PLOAM or divided slot rate controlled by the OLT.

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

Figure 14/G.983.1 – Frame format for 1244.16/155.52-Mbit/s PON

8.3.5.1.5 Frame structure for 1244/622-Mbit/s PON

In this case the downstream rate is exactly two times higher than the symmetric 622-Mbit/s case. This is shown in Figure 15.



a) Any ATM cell slot can contain an upstream PLOAM or divided slot rate controlled by the OLT.

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

Figure 15/G.983.1 – Frame format for 1244.16/622.08-Mbit/s PON

8.3.5.1.6 Time relation downstream-upstream frame

In Figures 11, 12, 13, 14 and 15, 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.

For the cases described in Figures 11, 12 and 14, 53 grants are mapped in the first two PLOAM cells of a frame and are numbered from 1 to 53; for the case described in Figures 13 and 15, 212 grants are mapped into the eight PLOAM cells in the frame, and are numbered 1-212. 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.

8.3.5.2 Physical layer cell identification

ITU-T Rec. I.361 identifies specific patterns for PLOAM flows. The following pattern is defined for maintenance of ATM-PONs. (See Table 7.)

Table 7/G.983.1 – PLOAM header

	Octet 1	Octet 2	Octet 3	Octet 4	Octet 5
Physical layer OAM cell for ATM-PON	0000 0000	0000 0000	0000 0000	0000 1101	HEC = valid code 0111 0110
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.					

8.3.5.3 Downstream PLOAM structure

Table 8 shows the contents of the payload of the downstream PLOAM cell. The first and third columns indicate the ordinal number of the payload bytes.

Table 8/G.983.1 – 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

Table 8/G.983.1 – Payload content of downstream PLOAM cell

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

8.3.5.3.1 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 11, or numbered "ATM cell 1" up to "ATM cell 216" in Figure 12 or 13, or numbered "ATM cell 1" up to "ATM cell 432" in Figure 14 or 15 that has a header equal to the specified header of a PLOAM cell, is discarded at the ONU in the ATM-specific TC layer.

8.3.5.3.2 PLOAM identification

Table 9 indicates the contents of the IDENT byte:

Table 9/G.983.1 – 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.

8.3.5.3.3 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 16.

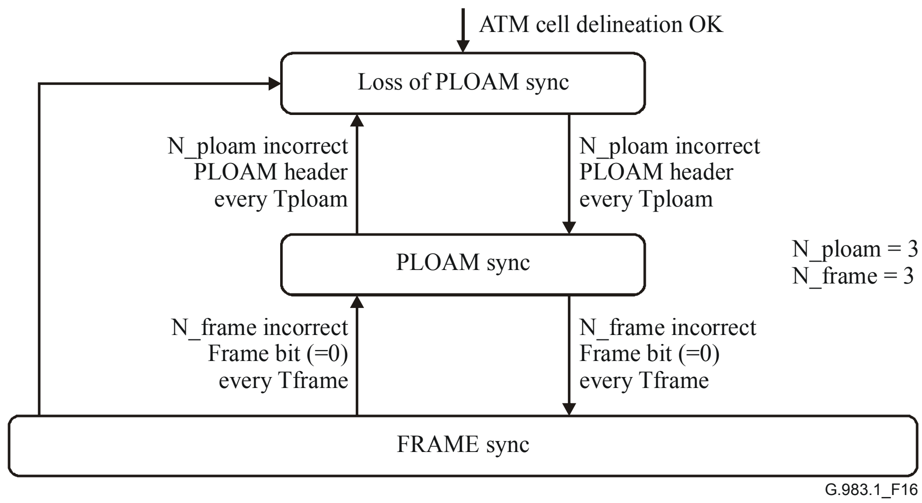


Figure 16/G.983.1 – Frame synchronization flow

8.3.5.3.4 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 four transmitted bytes. For the 1244-Mbit/s downstream case, this counter increments every eight 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 17.

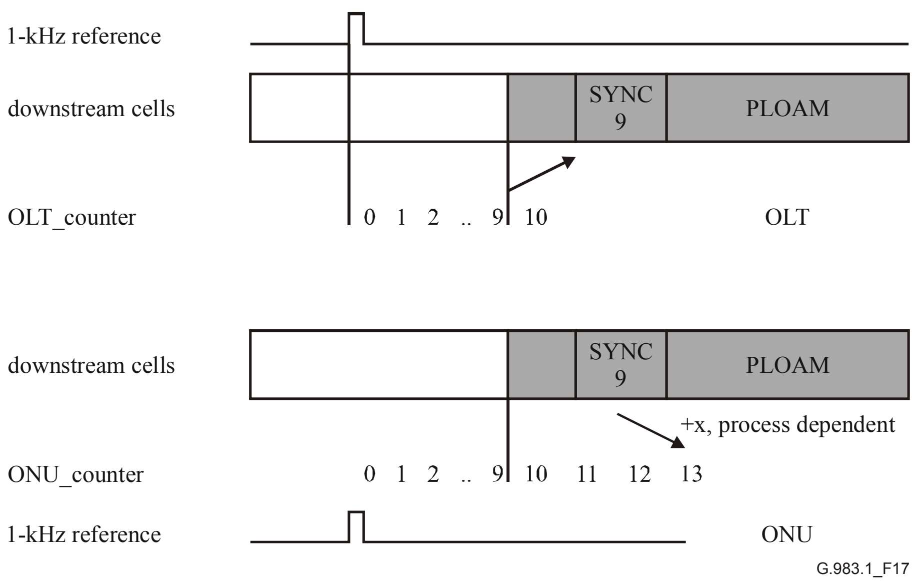


Figure 17/G.983.1 – 1-kHz reference extraction in ONU

8.3.5.3.5 Grants

Each PLOAM cell is filled with 27 grants. These grants are used by the ONUs for access on the upstream fibre. For the 155-Mbit/s upstream cases, 53 per frame are needed. The 53 active grants are mapped in the first two PLOAM cells of the downstream frame. For the 622-Mbit/s upstream cases, 212 per frame are needed. The 212 active grants are mapped into the first eight PLOAM cells of the downstream frame. The last grant of any even numbered PLOAM cell is filled with an idle grant. The grant fields of the remaining PLOAM cells for the asymmetrical cases are all filled with idle grants and hence will not be used by the ONU. The grant contents of the PLOAM cells are specified in Table 10. The length of a grant is 8 bits and the following types are defined in Table 10.

Table 10/G.983.1 – Specification of the grants

Type	Encoding	Definition
Data grant	Any value except 1111 1101 1111 1110 1111 1111	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 1111 1101 1111 1110 1111 1111	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 1111 1101 1111 1110 1111 1111	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. The usage of these grants is described in ITU-T Rec. G.983.4.
Reserved grants	Any value except 1111 1101 1111 1110 1111 1111	In a future version of this Recommendation other grant types will be used for specific data grants (e.g., to address a specific ONU interface or QoS class).
Ranging grant	1111 1101	Used for the ranging process. The condition to react to this grant is described in the ranging protocol.
Unassigned grant	1111 1110	For indicating an unused upstream slot.
Idle grant	1111 1111	For decoupling the downstream PLOAM rate from the upstream cell rate. These grants are ignored by the ONU.

	Number of grants per PLOAM				
Data rate (Mbit/s)	155/155	622/155	1244/155	622/622	1244/622
PLOAM 1	27	27	27	27	27
PLOAM 2	26	26	26	26	26
PLOAM 3	N/A	0	0	27	27
PLOAM 4	N/A	0	0	26	26
PLOAM 5	N/A	0	0	27	27
PLOAM 6	N/A	0	0	26	26
PLOAM 7	N/A	0	0	27	27
PLOAM 8	N/A	0	0	26	26
PLOAM 9-16	N/A	N/A	0	N/A	0

The OLT can address 32 ONUs at the same time and optionally it may address up to 64 ONUs.

8.3.5.3.6 Grants protection

A Cyclic Redundancy Check (CRC) protects a group of seven grants. The generating CRC polynomial for the grants is:

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

It can protect up to 15 bytes and has a Hamming distance of 4. It is able to detect up to three 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 seven 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 0s 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 six grants, a dummy seventh 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.

8.3.5.3.7 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 0s, 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 11 indicates the format of this message field.

Table 11/G.983.1 – 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.

8.3.5.3.8 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 $28 \times 53 - 1$ bytes or 1483 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}.

8.3.5.4 Upstream PLOAM structure

Table 12 shows the contents of the payload of the upstream PLOAM cell.

Table 12/G.983.1 – 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

8.3.5.4.1 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.

8.3.5.4.2 PLOAM identification

Table 13 indicates the contents of the IDENT byte.

Table 13/G.983.1 – Contents of IDENT field

Bits	Type	Encoding	
1..8	FU	all 0	For future use

8.3.5.4.3 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 0s, 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 14 indicates the format of this message field.

Table 14/G.983.1 – The format of message field

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 does not match the possible expected values related to this PON_ID, the message is discarded.
MESSAGE_ID	Indicates the type of message.
MESSAGE_FIELD	Contains the message.

8.3.5.4.4 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.

8.3.5.4.5 Laser Control Field (LCF)

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.

8.3.5.4.6 Receiver Control Field (RXCF)

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.

8.3.5.5 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 18.

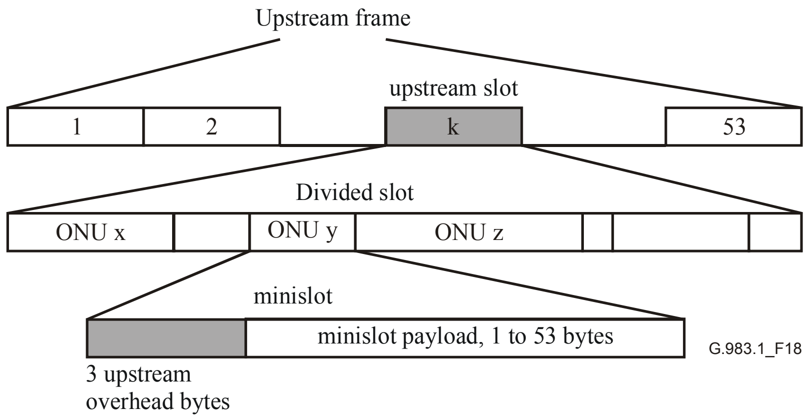


Figure 18/G.983.1 – Format of divided_slot

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 must be before or coincident with the end of the upstream slot. The three overhead bytes have the same definition as stated in Table 6. A more complete definition of divided slot function is given in ITU-T Rec. G.983.4.

8.3.5.6 Churning

Due to the multicast nature of the PON, downstream cells are churned at the TC layer with a churning key sent upstream by the ONU. The churning is performed for point-to-point downstream connections and churning can only be enabled or disabled per VP at its set-up. The churning key update rate is at least 1 update per second per ONU. If churning is not enough for a security requirement of a provided service, a suitable encryption mechanism should be employed at a higher layer than the TC layer to provide data scrambling.

8.3.5.6.1 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.

8.3.5.6.2 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.

8.3.5.6.3 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*not P14) + (X7*not P13*P14) + (X8*not P13*not P14)

K2 = (X3*P15*P16) + (X4*P15*not P16) + (X5*not P15*P16) + (X6*not P15*not P16)

where:

+	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*not P9)

K4 = (K1*not P9) + (K2*P9)

K5 = (K1*P10) + (K2*not P10)

K6 = (K1*not P10) + (K2*P10)

K7 = (K1*P11) + (K2*not P11)

K8 = (K1*not P11) + (K2*P11)

K9 = (K1*P12) + (K2*not P12)

K10 = (K1*not P12) + (K2*P12)

8.3.5.6.4 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 19 shows an example configuration of the churn function in OLT. The ATM header of the ATM cell is not churned. Only the payload of the cells is churned. Churning and dechurning of the downstream user data are performed byte by byte. In Figure 19, Y1 and Z1 are the MSB of the bytes, and Y8 and Z8 are the LSB of the bytes.

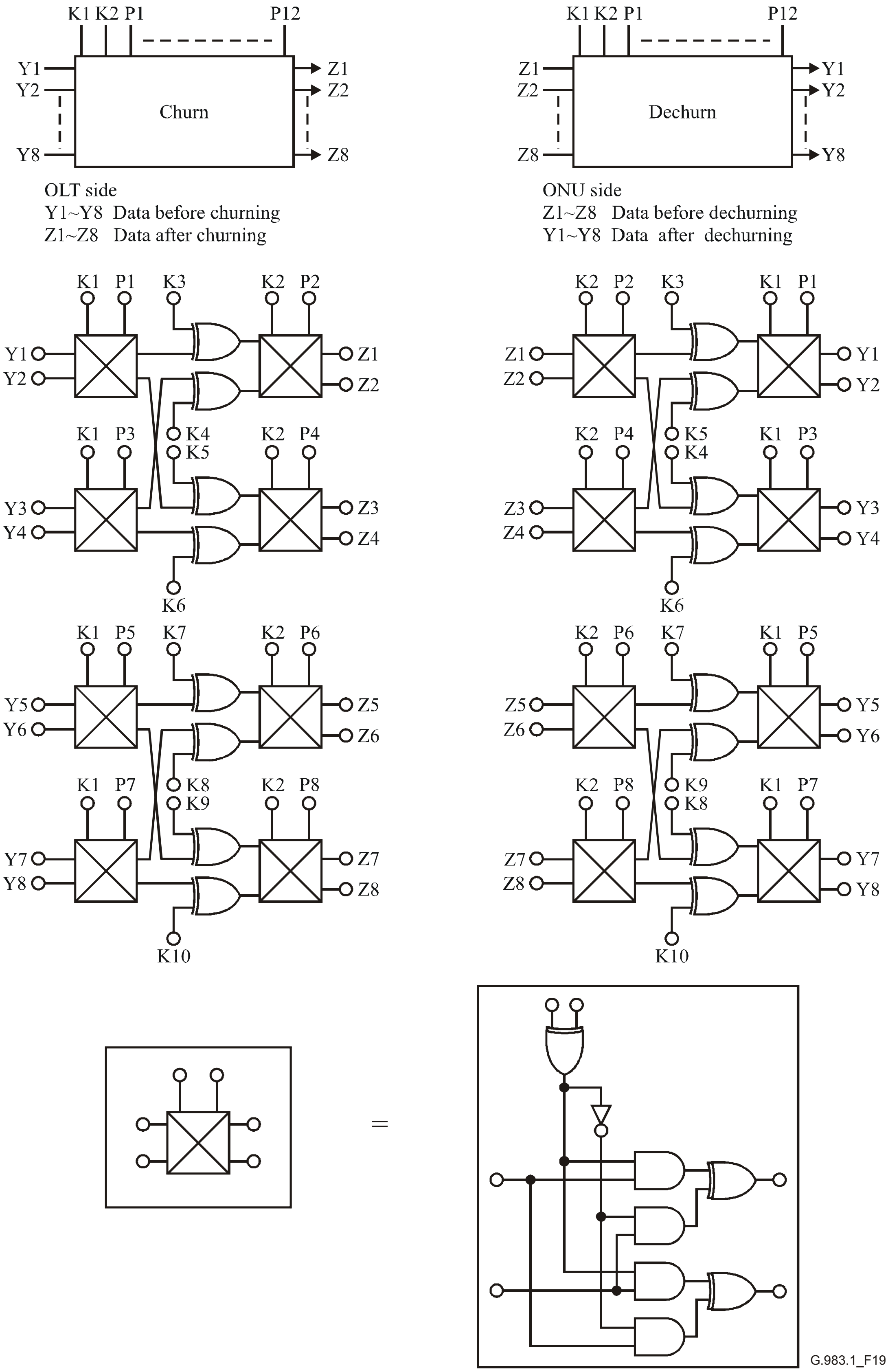


Figure 19/G.983.1 – Churning function

8.3.5.6.5 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 19 also shows an example configuration of the dechurn function in ONU.

8.3.5.6.6 Churning message flow

The churning key is provided by the ONU on the request from the OLT. Churned VPs for previously active ONU(s) should be restored when coming back to the PON. Churning for a ranged or reranged ONU starts after reception of the first key from this ONU. The churning message flow is shown in Figure 20.

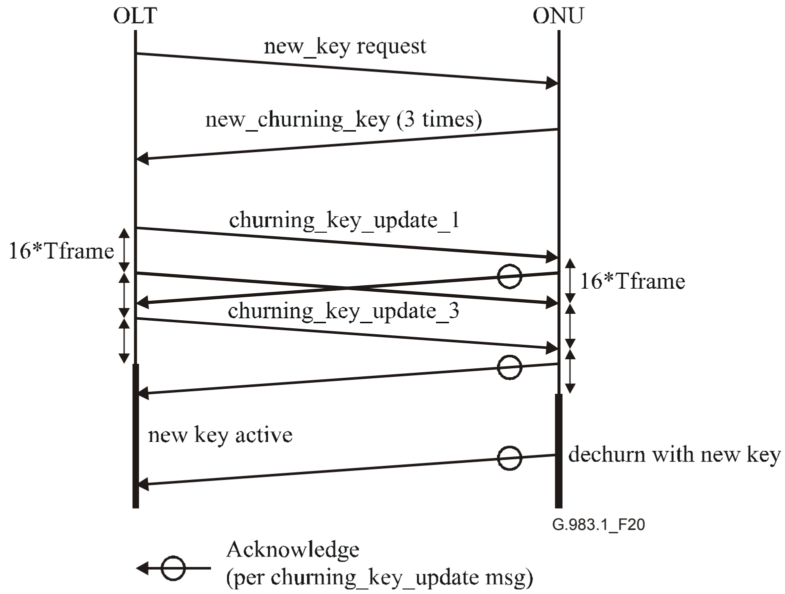


Figure 20/G.983.1 – Churning message flow

On receipt of the new_key_request message, the ONU responds with a new_churning_key. The ONU sends this message in three consecutive PLOAM cells. If the OLT receives three identical new keys, it sends a churning_key_update three times in 3 PLOAM cells with an appropriate interval of 16*Tframe between them to protect against loss of 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 16*Tframe after the third churning_key_update message. The ONU sends an Acknowledge message after each correctly received churning_key_update message. If the OLT receives no acknowledge after a time-out 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 can send a new_key_request if no new_churning_key is received on a previous request within a time-out of 300 ms; or it can send the new_key_request after activating the new key and having received at least one acknowledge.

The OLT indicates to the ONU which VPs are churned sending the churned_VP message three 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.

8.3.5.6.7 Advanced Security

As an option, the Advanced Encryption Standard (AES) may be used instead of churning to provide link security. Although there are several modes of operation for AES, only the Electronic Code Book (ECB) mode shall be used in BPON systems. The algorithm will be applied to the 48-byte payload of the cells. Note that since this payload is always an integral number of code blocks (3), no padding is needed. AES may be used for any of the BPON line-rates.

The format of the new big_key message is given in 8.3.8.2.2. This message is a unicast message, and it carried three information fields: the Key_Index, the Frag_Index, and the KeyBYTEs. This structure allows this message to carry keys of arbitrary size over the channel. The Key_Index field is used as a sequence number to make each set of key transmissions unique. The Frag_Index is used to re-assemble the multiple key transmissions. The KeyBYTEs carry 8 bytes of the key in each fragment.

The usage of these fields can be illustrated by the following example. Suppose the ONU is using-128-bit encryption keys, and it receives a 'New Churning Key Request Message'.

The sequence of events at the ONU would include:

– ONU creates a new random key: KeyBYTE0 through KeyBYTE15
– ONU increments the Key_Index
– ONU sends Big_Key message with Frag_Index=0, KeyBYTE0 through KeyBYTE7
– ONU sends Big_Key message with Frag_Index=1, KeyBYTE8 through KeyBYTE15
– ONU sends Big_Key message with Frag_Index=0, KeyBYTE0 through KeyBYTE7
– ONU sends Big_Key message with Frag_Index=1, KeyBYTE8 through KeyBYTE15
– ONU sends Big_Key message with Frag_Index=0, KeyBYTE0 through KeyBYTE7
– ONU sends Big_Key message with Frag_Index=1, KeyBYTE8 through KeyBYTE15

Note that the details of the key exchange, the key switchover, and alarms associated with churning are all unchanged.

8.3.5.7 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 requests a password, the ONU responds by sending its password three times. If it receives three identical passwords, the OLT declares this password as verified, and then attempts to validate the password.

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

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

8.3.5.8 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 three configure_VP/VC messages to an ONU, and expects an acknowledge within 300 ms after sending the last configure_VP/VC messages. If no acknowledge is received, the OLT detects the LOAi state anddeactivates the ONU.

8.3.5.9 Duplex PON system

In case of a duplex 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 must 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 as they are specified in ITU-T Rec. G.783 for performing Automatic Protection Switching. The complete description of this is given in ITU-T Rec. G.983.5.

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

8.3.5.10 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 set up 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.

8.3.6 ATM specific TC functions

8.3.6.1 Downstream

8.3.6.1.1 ATM cell format

The ATM cell is defined in ITU-T Rec. I.361.

8.3.6.1.2 Header error control

As defined in ITU-T Rec. I.432.

8.3.6.1.3 Cell delineation

Downstream cell delineation is performed in the ONU. An optional method is defined in ITU-T Rec. I.432.

8.3.6.1.4 Scrambler operation

As defined in ITU-T Rec. I.432 (distributed cell scrambler method for cell based transport systems).

8.3.6.1.5 Idle cells

Idle cells, as defined in ITU-T Rec. I.432, are inserted at the OLT and discarded at the ONU for cell rate decoupling.

8.3.6.1.6 PLOAM cells

Any cell, numbered "ATM cell 1" up to "ATM cell 54" in Figure 11, or numbered "ATM cell 1" up to "ATM cell 216" in Figure 12 or 13, or numbered "ATM cell 1" up to "ATM cell 432" in Figure 14 or 15 that has a header equal to the specified header of a PLOAM cell, is discarded at the ONU.

8.3.6.2 Upstream

8.3.6.2.1 ATM cell format

As defined in ITU-T Rec. I.361.

8.3.6.2.2 Header error control

The OLT applies HEC for the upstream as defined in ITU-T Rec. I.432 for every single ONU.

8.3.6.2.3 Cell delineation

Since upstream cells arrive from different ONUs with different phase, the OLT keeps n state diagrams for n active ONUs. Figure 21 shows the state diagram of one ONU.

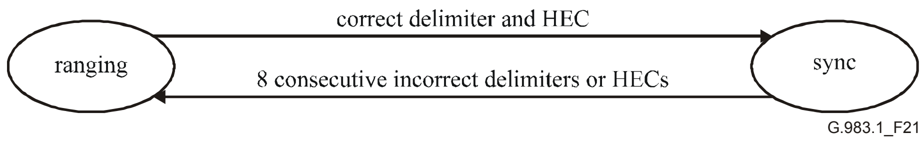


Figure 21/G.983.1 – Cell delineation state diagram

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 Rec. I.432.1. After one correct delimiter and HEC, the ONU is declared in sync. For eight 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.

8.3.6.2.4 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 22. This pattern is added modulo 2 to each upstream cell or minislot. The upstream overhead bytes are not scrambled.

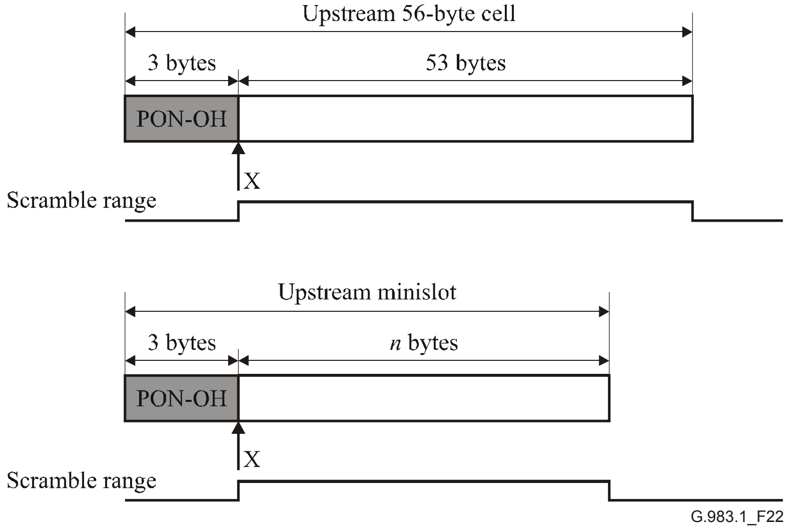


Figure 22/G.983.1 – Upstream scrambler

The implementation of this scrambler should be functionally equivalent to the one shown in Figure 23.

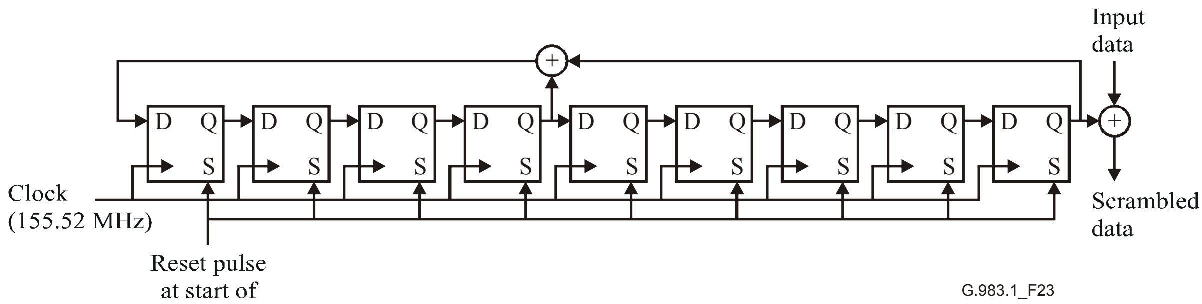


Figure 23/G.983.1 – Upstream scrambler

All FFs are set at 1 by the reset pulse.

8.3.6.2.5 Idle cells

The ONU sends an idle cell, as defined in ITU-T Rec. I.432, 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.

8.3.6.2.6 PLOAM cells

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

8.3.7 OAM functions

The OAM functions installed in the ONU and OLT are shown in Figure 24. 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 Rec. I.610 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 can not do anything with these notifications.

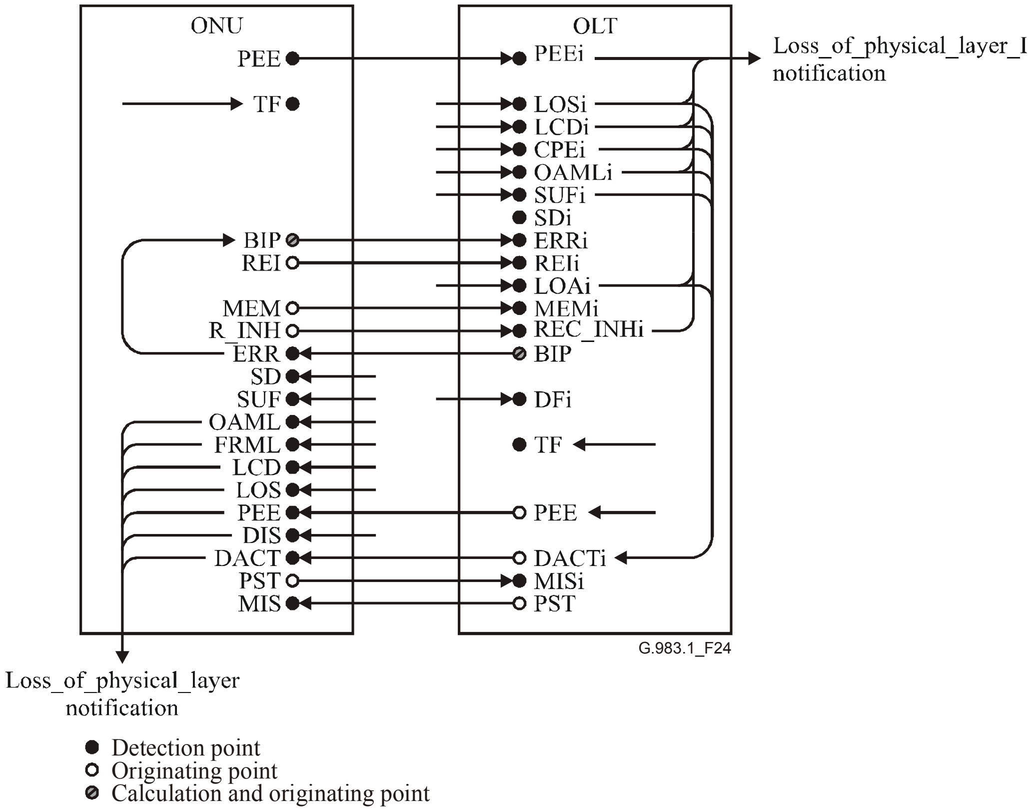


Figure 24/G.983.1 – OAM functions

8.3.7.1 Items detected at OLT

Table 15/G.983.1 – 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 ONUi has failed *n* times (*n* = 2; refer to 8.4.4.3.3) while the OLT has received optical bursts from this ONU.	Send three times deactivate_PON_ID messages.
	The ONU is reranged successfully.	
PEEi	**Physical Equipment Error of ONUi**	
	When the OLT receives a PEE from the ONU	Generate Loss_of_physical_layer_I notification.
	When the OLT does not receive a PEE message from the ONUi in three seconds	Stop Loss_of_physical_layer_I notification.
LCDi	**Loss of Cell Delineation of ONUi**	
	When eight consecutive invalid delimiters or invalid HECs from ONUi are received	Send three times deactivate_PON_ID messages. Generate Loss_of_physical_layer_I notification.
	When cell delineation for ONUi is achieved in the operating state	
OAMLi	**PLOAM cell loss for ONUi**	
	When three consecutive PLOAM cells of ONUi are missing	Send three times deactivate_PON_ID messages. Generate Loss_of_physical_layer_I notification.
	When the OLT receives a PLOAM cell corresponding to its PLOAM grant in the Operating state	
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 three times deactivate_PON_ID messages. Generate Loss_of_physical_layer_I notification.
	When the OLT receives a cell in the correct position in the operating state	

Table 15/G.983.1 – Items detected at OLT

Type	Description	
LOSi	**Loss of signal of ONUi**	
	No valid optical signal at the O/E receiver received for ONUi when expected during eight upstream sequential cells	Send three times deactivate_PON_ID messages. Generate Loss_of_physical_layer_I notification.
	When the OLT receives a valid optical signal corresponding to its grant in the Operating state	
LOAi	**Loss of Acknowledge with ONUi**	
	The OLT does not receive an acknowledge from ONUi after a set of downstream messages that imply an upstream acknowledge	Send three times deactivate_PON_ID messages. Generate Loss_of_physical_layer_I notification.
	When the OLT receives an acknowledge	
DFi	**Deactivate Failure of ONUi**	
	The ONU does not react correctly after three DACT messages	
	Cancelled by the operator	
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 cleared when the next upstream PLOAM cell with a BIP8 that matches the calculated BIP8 is received at the OLT from ONUi	
SDi	**Signal Degraded of ONUi**	
	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 $\geq 10^{-5}$, this state is entered.	
	When the upstream BER of ONUi becomes $<10^{-5}$, this state is cleared.	

Table 15/G.983.1 – Items detected at OLT

Type	Description	
REIi	**Remote Error Indication of ONUi**	
	When the OLT receives a non-zero REI message, it issues REIi.	
	REIi should be cleared when an REI message reporting zero errors is received at OLT from ONUi.	
MEMi	**Message_Error Message from ONUi**	
	When the OLT receives an unknown message from ONUi or received message_error message	
	When the operator is informed	
R-INHi	**Receive Alarm Inhibition of ONUi**	
	When the OLT receives R-INH message from ONUi, R-INHi is detected	Ignore received alarms from this ONU. Generate Loss_of_physical_layer_I notification.
	When the OLT receives a PLOAM cell in the ranging process of ONUi	–
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 the same	

8.3.7.2 Items detected at ONU

Table 16/G.983.1 – Items detected at 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. E.g., this can be generated by the logical function (OAML.AND.FRML.AND.LCD).	Switch off laser. Generate Loss_of_physical_layer notification.
	Valid optical signal. E.g., this can be generated by the negated logical function given above.	

Table 16/G.983.1 – Items detected at ONU

Type	Description	
PEE	**Physical_Equipment_error Signal**	
	When the ONU receives a PEE message	Generate Loss_of_physical_layer notification.
	When the ONU does not receive a PEE message in three 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 three consecutive PLOAM headers are wrong	Switch off laser. Generate Loss_of_physical_layer notification.
	OAM sync when three consecutive correct PLOAM headers	
LCD	**Loss of Cell Delineation**	
	When seven consecutive ATM cells have an invalid HEC	Switch off laser. Generate Loss_of_physical_layer notification.
	When N consecutive ATM cells have correct HEC ($N = 9$ or 17)	
FRML	**FRML Loss of downstream frame**	
	When the frame bit is "0" for three consecutive frames.	Switch off laser. Generate Loss_of_physical_layer notification.
	When frame bit is "1" for three consecutive frames	
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 $\geq 10^{-5}$	
	Set inactive when the downstream BER is $<10^{-5}$	
MEM	**Message Error Message**	
	When the ONU receives an unknown message	Send upstream Message_error message.

Table 16/G.983.1 – Items detected at ONU

Type	Description	
DACT	**Deactivate PON_ID**	
	Reception of the Deactivate_PON_ID message addressed to this ONU, requesting the ONU to deactivate itself	Switch off the laser and go to state O2. Generate Loss_of_physical_layer notification
	Reception of Upstream_overhead message	Proceed with normal ranging procedures.
DIS	**Disabled ONU**	
	When the ONU receives a Disable_serial_number message with its own serial number and the enable flag = 0xFF. It stays in this state even after power-off	Switch off laser. Go to Emergency Stop State O9. Generate Loss_of_physical_layer notification
	When the ONU receives a Disable_serial_number message with Enable flag = 0x0F or when it receives a Disable_serial_number message with its own serial number and the enable flag = 0x00	Go to state O1.
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.	

8.3.8 MESSAGES in the PLOAM channel

The processing time of all downstream messages is within 6*Tframe, which is the time needed by the ONU to process the downstream message and prepare any corresponding upstream action. The downstream churning_key_update message has priority on all other downstream messages. The priority level is indicated in the "function" column. On some messages, the ONU has to reply with an upstream message. The priority level of upstream messages is also indicated in the "function" column. If not indicated, the priority level is 0 (0 is lowest priority).

Also note that the special messages Divided_Slot_Grant_configuration and PST are not used in systems without DBA or duplex protection. However, all systems should be able to receive such messages without causing an error. For further description of the detailed behaviour, refer to ITU-T Recs G.983.4 and G.983.5 for these messages.

8.3.8.1 Message definition

See Table 17.

Table 17/G.983.1 – Message definition

	Message name	Function	Direction	Trigger	Number of times sent	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	OLT needs a new key for the churning mechanism.	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 (Te) 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 (Te).
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.

Table 17/G.983.1 – Message definition

	Message name	Function	Direction	Trigger	Number of times sent	Effect of receipt
7	Ranging_time	It indicates the value expressed in number of upstream bits that an ONU with PON_ID must fill in into its equalization delay register (Td).	OLT → ONU	When the OLT decides that the delay (Td) must be updated; see ranging protocol	3	The ONU fills in the equalization delay (Td) 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, LOAi, SUFi or CPEi are detected	3	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	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.
10	Churning_key_update	To indicate to the ONU when the new churning key becomes valid Priority level is 1.	OLT → ONU	When the OLT is ready to churn data for ONU with PON_ID	3	The ONU switches to the new churning key 48*Tframe after the first update message. Send one acknowledge after each correctly received 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.

Table 17/G.983.1 – Message definition

	Message name	Function	Direction	Trigger	Number of times sent	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 message activates or deactivates a VP/VC in downstream and upstream for communication at the ATM layer.	OLT → ONU	When the OLT wants to set up 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. Send one acknowledge after each correctly received message.
14	BER_interval	It defines the accumulation interval per ONU expressed in the number of downstream frames for the ONU counting the number of downstream bit errors. Same time-out as for Configure_VP/VC	OLT → ONU	OpS defines this interval and can focus on one particular ONU.	3	The ONU starts a BER_interval timer and accumulates the downstream bit errors. Send one acknowledge after each correctly received message. 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.

Table 17/G.983.1 – Message definition

	Message name	Function	Direction	Trigger	Number of times sent	Effect of receipt
16	Physical_equipment_ error message (PEE)	To indicate to the ONUs that the OLT is unable to send both ATM cells and OMCC cells in the direction from ATM layer to TC layer	OLT → ONU	When the OLT detects it cannot send both ATM cells and OMCC cells in the direction from ATM layer to TC layer	1 time/second	Depends on the system
17	Churned_VP	To indicate to the ONUs which VP/VC are churned or not	OLT → ONU	When a new VP must be churned or not	3	(Un)Mark this VP as churning. Send one acknowledge after each correctly received message.
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 three 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 standby state 3 (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 an 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.

Table 17/G.983.1 – Message definition

	Message name	Function	Direction	Trigger	Number of times sent	Effect of receipt
22	New_churning_key	Contains a new key to be used on the downstream churned cells to this ONU Priority level is 1.	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 three consecutive identical keys and switches to the new key 48*Tframe after the first churning_key_update message.
23	Acknowledge	It is used by the ONU to indicate the reception of a downstream Configure_VP/VC, Churning_key_update, Churned_VP or BER_interval message. Priority is 1 for the acknowledge on the churning_key_update message. The priority level is 0 for the others. The time-out for the acknowledge is 300 ms.	OLT ← ONU	After receiving every correct corresponding downstream message	1 time	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.	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.

Table 17/G.983.1 – Message definition

	Message name	Function	Direction	Trigger	Number of times sent	Effect of receipt
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	3	Inform the operator
26	REI (Remote Error Indication)	It contains the number of downstream BIP mismatches (one count per bit mismatch) 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	R-INH	To inform the OLT that the ONU will power-off in a normal operation. This is to prevent the OLT from issuing unnecessary alarm reports. Priority level is 2.	OLT ← ONU	The ONU generates this message when the power-off (such as the power switch-off or the power cord extraction without battery backup) is activated in a normal operation.	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 send both ATM cells and OMCC cells in the direction from ATM layer to TC layer	OLT ← ONU	When the ONU detects it cannot send both ATM cells and OMCC Cells in the direction from ATM layer to TC layer	1 time/second	Depends on the system.

Table 17/G.983.1 – Message definition

	Message name	Function	Direction	Trigger	Number of times sent	Effect of receipt
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 three identical passwords, it is declared as valid. Further processing is system dependent.
31	Vendor_specific message	A number of Message_Ids are reserved for vendor-specific messages.	OLT ← ONU	Vendor-specific	Vendor-specific	Vendor-specific
32	Big_Key message (optional)	Carries a large key for use with data encryption Priority level is 1.	OLT ← ONU	After the OLT request, the ONU fetches a new key and sends it to the OLT	3 times per fragment	The OLT initializes the encryption logic with this new key if it receives three consecutive identical keys and switches to the new key 48*Tframe after the first churning_key_update message.

8.3.8.2 Message formats

This clause defines the contents of the messages in the previous clause.

8.3.8.2.1 Downstream message formats

No message		
Octet	**Content**	**Description**
35	0100 0000	Broadcast message to all ONUs
36	0000 0000	Message identification "no message"
37..46	Unspecified	

Upstream_Rx_Control message		
Octet	**Content**	**Description**
35	0100 0000	Broadcast message to all ONUs
36	0000 0001	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	dddd dddd	RXCF1 for *n* = 0x00 and RXCF10 for *n* = 0x01
39	dddd dddd	RXCF2 for *n* = 0x00 and RXCF11 for *n* = 0x01
40	dddd dddd	RXCF3 for *n* = 0x00 and RXCF12 for *n* = 0x01
41	dddd dddd	RXCF4 for *n* = 0x00 and RXCF13 for *n* = 0x01
42	dddd dddd	RXCF5 for *n* = 0x00 and RXCF14 for *n* = 0x01
43	dddd dddd	RXCF6 for *n* = 0x00 and RXCF15 for *n* = 0x01
44	dddd dddd	RXCF7 for *n* = 0x00 and RXCF16 for *n* = 0x01
45	dddd dddd	RXCF8 for *n* = 0x00 and unspecified for *n* = 0x01
46	dddd dddd	RXCF9 for *n* = 0x00 and unspecified for *n* = 0x01

Upstream_overhead message		
Octet	**Content**	**Description**
35	0100 0000	Broadcast message to all ONUs
36	0000 0010	Message identification "Upstream_overhead"
37	gggg gggg	Number of guard bits of the upstream overhead, count starting from the first bit of the upstream overhead bytes ($4 \leq$ gggggggg ≤ 24). The value of the first gggg gggg bits of overhead data in bytes 38-40 are ignored by the ONU.
38	bbbb bbbb	Data to be programmed in overhead byte 1
39	bbbb bbbb	Data to be programmed in overhead byte 2
40	bbbb bbbb	Data to be programmed in overhead byte 3
41	Unspecified	
42	Unspecified	

Upstream_overhead message		
Octet	**Content**	**Description**
43	xxxx xxxp	Message identification "preassigned equalization delay (Te)" p = "0" indicates Te = 0 p = "1" indicates Te is defined by octets 44-46
44	dddd dddd	MSB of pre-assigned equalization delay (Te)
45	dddd dddd	
46	dddd dddd	LSB of pre-assigned equalization delay (Te)

Ranging_time message		
Octet	**Content**	**Description**
35	PON_ID	Directed message to one ONU
36	0000 0011	Message identification "Ranging_time"
37	dddd dddd	MSB of equalization_delay (Td)
38	dddd dddd	
39	dddd dddd	LSB of equalization_delay (Td)
40..46	Unspecified	

Serial_number_mask message		
Octet	**Content**	**Description**
35	0100 0000	Broadcast message to all ONUs
36	0000 0100	Message identification "Serial_number_mask"
37	nnnn nnnn	Number of valid bits (nnnnnnnn ≤ 64), count started from LSB of byte 45 counting up to the MSB of byte 38
38	abcd efgh	Serial number byte 1
…	…	
45	stuv wxyz	Serial number byte 8
46	Unspecified	

Assign_PON_ID message		
Octet	**Content**	**Description**
35	0100 0000	Broadcast message to all ONUs
36	0000 0101	Message identification "Assign_PON_ID"
37	pppp pppp	PON_ID (pppppppp ≤ 63)
38	abcd efgh	Serial number byte 1
…	…	
45	stuv wxyz	Serial number byte 8
46	Unspecified	

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	0000 0110	Message identification "Deactivate_PON_ID"
37..46	Unspecified	

Disable_serial_number message		
Octet	**Content**	**Description**
35	0100 0000	Broadcast message to all ONU
36	0000 0111	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 bytes 38~45 are irrelevant. 0x00: The ONU with this serial number can participate in the ranging process.
38	abcd efgh	Serial number byte 1
…	…	
45	stuv wxyz	Serial number byte 8
46	Unspecified	

New_churning_key_request message		
Octet	**Content**	**Description**
35	PON_ID	Directed message to one ONU
36	0000 1000	Message identification "New_churning_key_request"
37..46	Unspecified	

Churning_key_update message		
Octet	**Content**	**Description**
35	PON_ID	Directed message to one ONU
36	0000 1001	Message identification "Churning_key_update"
37	COUNT	Goes from 1 to 3
38..46	Unspecified	

Grant_allocation message		
Octet	**Content**	**Description**
35	PON_ID	Directed message to one ONU
36	0000 1010	Message identification "Grant_allocation"
37	dddd dddd	Data grant allocated to the ONU with this PON_ID
38	0000 000a	a:1 = Activate data grant for this ONU a:0 = Deactivate data grant for this ONU
39	pppp pppp	PLOAM grant allocated to the ONU with this PON_ID
40	0000 000a	a:1 = Activate PLOAM grant for this ONU a:0 = Deactivate PLOAM grant for this ONU
41..46	Unspecified	

Divided_Slot_Grant_configuration message		
Octet	**Content**	**Description**
35	PON_ID	Directed message to one ONU
36	0000 1011	Message identification "Divided_Slot_Grant_configuration"
37	0000 000a	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 [1 .. (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 0000 0000 is used for the MAC protocol. Other values are for FU.
42..46	Unspecified	

Configure VP/VC message		
Octet	**Content**	**Description**
35	PON_ID	Directed message to one ONU
36	0000 1100	Message identification "Configure VP/VC"
37	0000 000a	Bytes 38-41 define downstream and 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

Configure VP/VC message		
Octet	**Content**	**Description**
41	HEADER4	ATM header byte 4 (LSB). The 4 least significant bits (PTI and CLP) are transparent for the TC layer.
42	MASK1	All the bits of MASK that are set to 1 define the corresponding bits in HEADER that must be used for termination or generation of cells at the ATM layer.
43	MASK2	
44	MASK3	
45	MASK4	Only the 4 most significant bits are used.
46	Unspecified	

Physical_equipment_error message		
Octet	**Content**	**Description**
35	0100 0000	Broadcast message to all ONUs
36	0000 1101	Message identification "Physical_equipment_error"
37..46	Unspecified	

Request_Password message		
Octet	**Content**	**Description**
35	PON_ID	Directed message to one ONU
36	0000 1110	Message identification "Request_Password"
37..46	Unspecified	

Churned_VP message		
Octet	**Content**	**Description**
35	PON_ID	Directed message to one ONU
36	0000 1111	Message identification "Churned_VP"
37	xxxx xxxa	a = 1 Churned a = 0 Not churned
38	abcd efgh	abcdefgh = VPI[11..4]
39	ijkl 0000	ijkl = VPI[3..0]
40..46	Unspecified	

POPUP message		
Octet	**Content**	**Description**
35	0100 0000	Broadcast message to all ONUs
36	0001 0000	Message identification "POPUP"
37..46	Unspecified	

Vendor_specific message		
Octet	**Content**	**Description**
35	xxxx xxxx	Directed message to one ONU or broadcast
36	0111 1zzz	Message identification "Vendor_specific"
37..46	yyyy yyyy	Vendor specific. These messages can be used for proprietary use by different vendors and will never be standardized.

PST message		
Octet	**Content**	**Description**
35	0100 0000	Broadcast message to all ONUs
36	1000 0000	Message identification "PST"
37	Line number	Can be 0 or 1
38	Control	This is the K1 byte as specified in ITU-T Rec. G.783.
39	Control	This is the K2 byte as specified in ITU-T Rec. G.783.
40..46	Unspecified	

BER_interval message		
Octet	**Content**	**Description**
35	PON_ID	Directed message to one ONU
36	1000 0001	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	

8.3.8.2.2 Upstream message formats

No message		
Octet	**Content**	**Description**
2	PON_ID	Indicates the ONU sourcing this message
3	0000 0000	Message identification "no message"
4..13	Unspecified	

New_churning_key message		
Octet	**Content**	**Description**
2	PON_ID	Indicates the ONU sourcing this message
3	0000 0001	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	

Acknowledge message		
Octet	**Content**	**Description**
2	PON_ID	Indicates the ONU sourcing this message
3	0000 0010	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

Serial_number_ONU		
Octet	**Content**	**Description**
2	0100 0000 PON_ID	Operating standby state 2 Operating standby state 3
3	0000 0011	Message identification "Serial_number_ONU"
4	0000 0000	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	VID4	Vendor_ID byte 4
9	VSSN1	Vendor specific Serial number byte 1
10	VSSN2	Vendor specific Serial number byte 2
11	VSSN3	Vendor specific Serial number byte 3
12	VSSN4	Vendor specific Serial number byte 4
13	Unspecified	

The codeset for the Vendor_ID is specified in ANSI T1.220. The four characters are mapped in the 4 byte field by taking each ASCII/ANSI character code and concatenating them.

Example: Vendor_ID = ABCD ⇒ VID1 = 0x41, VID2 = 0x42, VID3 = 0x43, VID4 = 0x44.

Password message		
Octet	**Content**	**Description**
2	PON_ID	Indicates the ONU sourcing this message
3	0000 0100	Message identification "Password"
4	pppp pppp	Password1
…	…	…
13	pppp pppp	Password10

Physical_equipment_error message		
Octet	**Content**	**Description**
2	PON_ID	Indicates the ONU sourcing this message
3	0000 0101	Message identification "Physical_equipment_error"
4..13	Unspecified	

Vendor_specific message		
Octet	**Content**	**Description**
2	xxxx xxxx	Indicates ONU sourcing this message
3	0111 1zzz	Message identification "Vendor_specific"
4..13	yyyy yyyy	Vendor-specific. These messages can be used for proprietary use by different vendors and will never be standardized.

REI message		
Octet	**Content**	**Description**
2	PON_ID	Indicates the ONU sourcing this message
3	1000 0000	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	0000 SSSS	Sequence number. The 4 LSB bits SSSS are incremented every time this message is sent
9..13	Unspecified	

R-INH message		
Octet	**Content**	**Description**
2	PON_ID	Indicates the ONU sourcing this message
3	1000 0001	Message identification "R-INH"
4..13	Unspecified	

PST message		
Octet	**Content**	**Description**
2	PON_ID	Indicates the ONU sourcing this message
3	1000 0010	Message identification "PST"
4	Linenumber	Can be 0 or 1
5	Control	This is the K1 byte as specified in ITU-T Rec. G.783.
6	Control	This is the K2 byte as specified in ITU-T Rec. G.783.
7..13	Unspecified	

Message_error message		
Octet	**Content**	**Description**
2	PON_ID	Indicates the ONU sourcing this message
3	1000 0011	Message identification "Message_error"
4	Message_id	Indicates unrecognized downstream message_id
5..13	Unspecified	

Big_Key Message (optional)		
Octet	**Content**	**Description**
2	PON_ID	Indicates the ONU sourcing this message
3	0000 0110	Message identification "Big Churning Key message"
4	Key_Index	Index indicating which ONU key this message carries
5	Frag_Index	Index indicating which part of the key this message carries
6	KeyBYTE0	Byte 0 of fragment (Frag_Index) of Key (Key_Index)
7	KeyBYTE1	Byte 1 of fragment (Frag_Index) of Key (Key_Index)
8	KeyBYTE2	Byte 2 of fragment (Frag_Index) of Key (Key_Index)
9	KeyBYTE3	Byte 3 of fragment (Frag_Index) of Key (Key_Index)
10	KeyBYTE4	Byte 4 of fragment (Frag_Index) of Key (Key_Index)
11	KeyBYTE5	Byte 5 of fragment (Frag_Index) of Key (Key_Index)
12	KeyBYTE6	Byte 6 of fragment (Frag_Index) of Key (Key_Index)
13	KeyBYTE7	Byte 7 of fragment (Frag_Index) of Key (Key_Index)

8.3.9 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 8.3.8.2.1 and 8.3.8.2.2. A complete description of APS function is given in ITU-T Rec. G.983.5. See Annex D for further details.

Time required for APS including ranging time for 32 ONUs shall be considered to support POTS and/or ISDN services; on-going connections should not be disconnected when APS is carried out.

8.4 Ranging method

8.4.1 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 a *priori* 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.

8.4.1.1 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.

8.4.1.2 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.

8.4.1.2.1 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.

8.4.1.2.2 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.

8.4.1.2.3 Warm PON, warm ONU

This situation is characterized by a previously active ONU which remains powered-on and connected to an active PON but be in the POPUP state described in 8.4.4.2.1. Also, this situation includes an active ONU connected to an active PON with running traffic.

8.4.1.2.4 Switch over

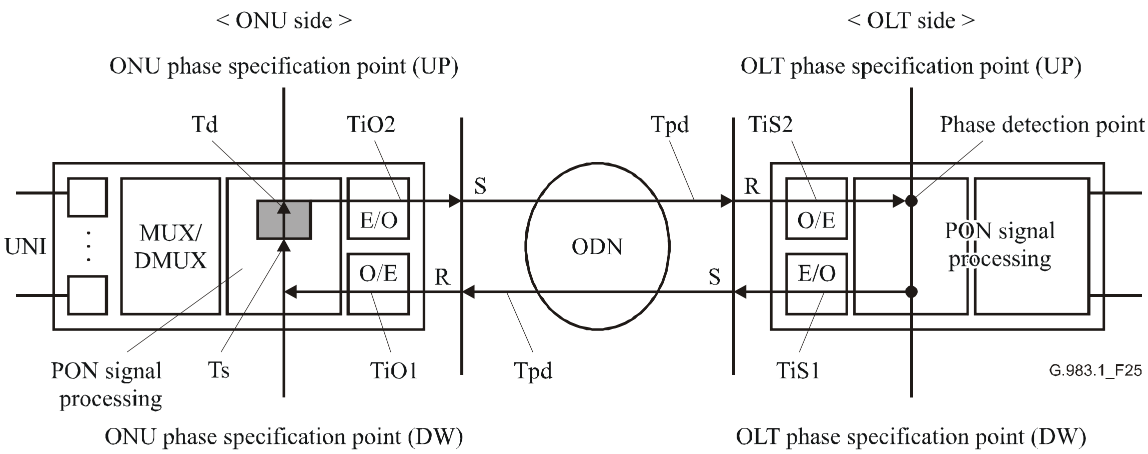
There can be several types of possible duplex and/or partially duplexed ATM-PON configurations. The ranging protocol should be applicable in these cases.

8.4.2 Phase relation specification between downstream and upstream

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

8.4.2.1 Definition of the phase specification points

Configuration of the specification points described below is shown in Figure 25.



Tconst = TiS1 + Tpd + TiO1 + Ts + Td + TiO2 + Tpd + TiS2

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

= TiO1 + Ts + TiO2

$0 \le$ Td (Equalization_delay) $\le$ Max

Figure 25/G.983.1 – Configuration of the specification points

8.4.2.1.1 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.

8.4.2.1.2 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.

8.4.2.1.3 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.

8.4.2.1.4 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 TiO1. Cells in the upstream transmission at the ONU phase specification point reach the Reference point S of the ONU after TiO2.

Also, cells in the downstream transmission at the OLT phase specification point reach the Reference point S of the OLT after a certain delay TiS1. Cells in the upstream transmission at the Reference point R of the OLT reach the OLT phase specification point after TiS2.

The delays, TiO1, TiO2, TiS1 and TiS2 are due to optoelectrical and electro-optical conversion in the ONU and OLT (see Figure 25).

8.4.2.2 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 multivendor environments.

The response time Tresponse(ONU) is defined below:

$$\text{Tresponse(ONU)} = \text{TiO1} + \text{Ts} + \text{Td} + \text{TiO2 (at Td = 0)}$$

$$= \text{TiO1} + \text{Ts} + \text{TiO2}$$

The value of Tresponse(ONU) shall be between 3136 and 4032 bits (at 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.

$$3136 \text{ bits} \leq \text{Tresponse(ONU)} \leq 4032 \text{ bits (at 155.52 Mbit/s)}$$

$$6272 \text{ bits} \leq \text{Tresponse(ONU)} \leq 8064 \text{ bits (at 622.08 Mbit/s)}$$

NOTE – The delay variation due to Tresponse(ONU) is considered as an ONU location ambiguity of about the equivalent of 600 m and 300 m for upstream rates of 155 and 622 Mbit/s, respectively.

8.4.2.3 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 26. Tpd represents the optical fibre 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).

$$\text{Teqd} = 2{*}\text{Tpd} + \text{Ts} + \text{Td} + \text{TiO1} + \text{TiO2} + \text{TiS1} + \text{TiS2}$$

$$= 2{*}\text{Tpd} + \text{Tresponse(ONU)} + \text{Td} + \text{TiS1} + \text{TiS2}$$

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 (at 155.52 Mbit/s)

the maximum value of Td ≥ 128 000 bits (at 622.08 Mbit/s)

The maximum round-trip delay of about 200 µs (equal to 20 km optical fibre) 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 (at 155.52 Mbit/s).

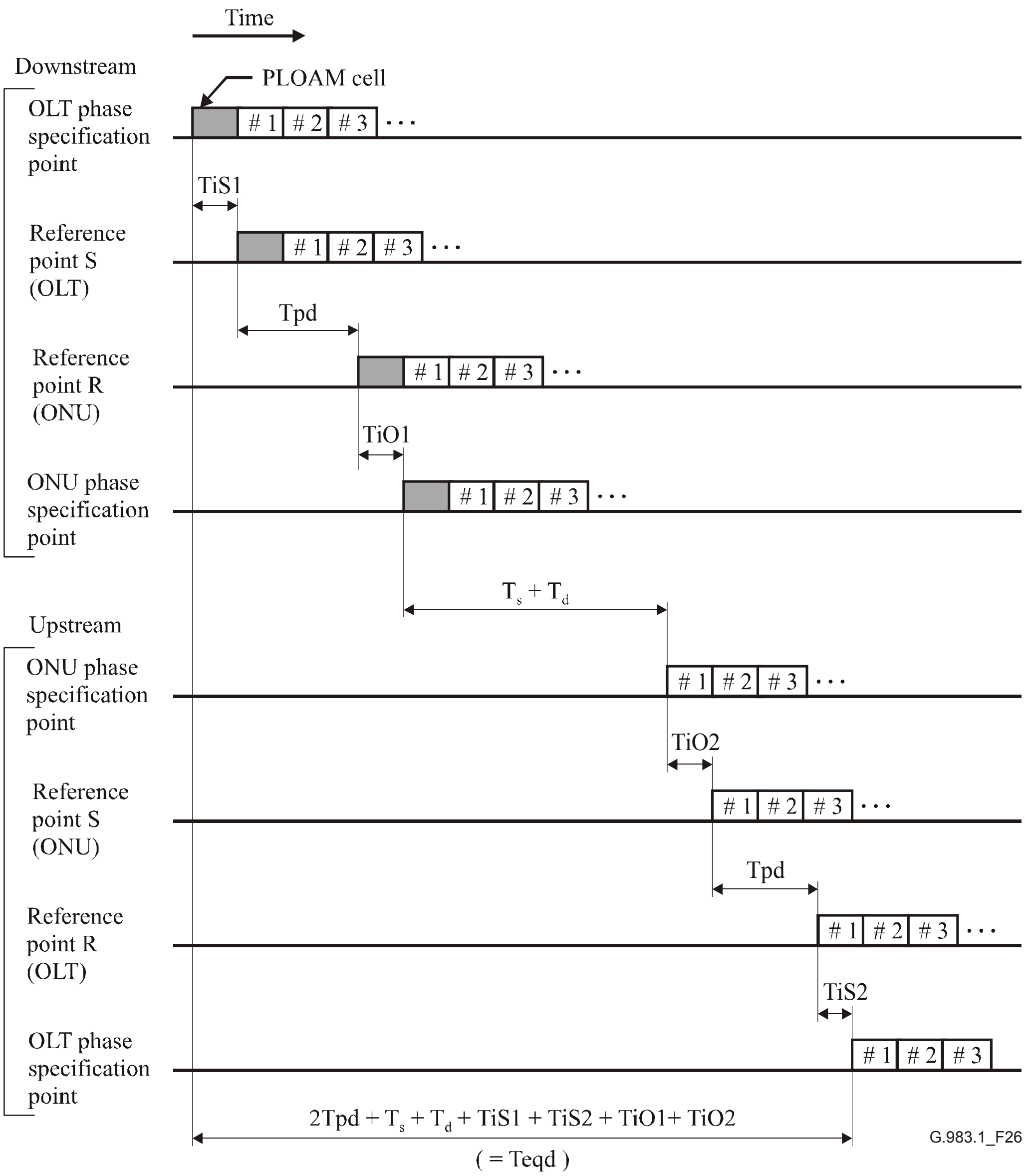


Figure 26/G.983.1 – Phase relationship between downstream and upstream

8.4.2.4 Granularity of the equalization_delay

The equalization_delay (Td) should be defined with a granularity of 1 bit for all rates.

8.4.2.5 Opening the ranging window in the ranging procedure

NOTE – The following text presents examples that use 155.52 Mbit/s for the upstream rate. The values given for Tresponse and Td depend on the upstream rate. Therefore, these values do not apply to the 622 Mbit/s case. See the specifications above for those values.

8.4.2.5.1 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

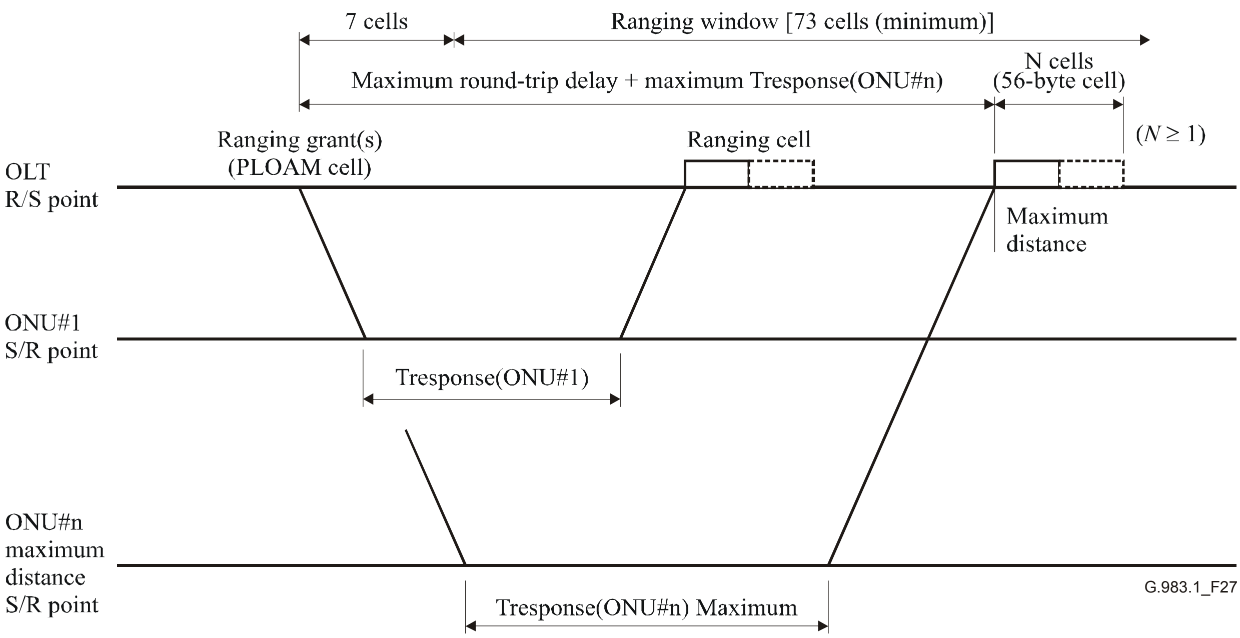
– additional ranging grants or PLOAM grants if necessary.

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 8.4.4.1) is applied, the ONU may use grants for the ONU optical power set-up. Also, if the OLT periodically initiates 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 27 for the case where the ranging grant is located in the first grant field in the first PLOAM cell of the downstream frame.



NOTE – 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 27/G.983.1 – Ranging window and phase relation

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

NOTE – 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 in Figure 27.

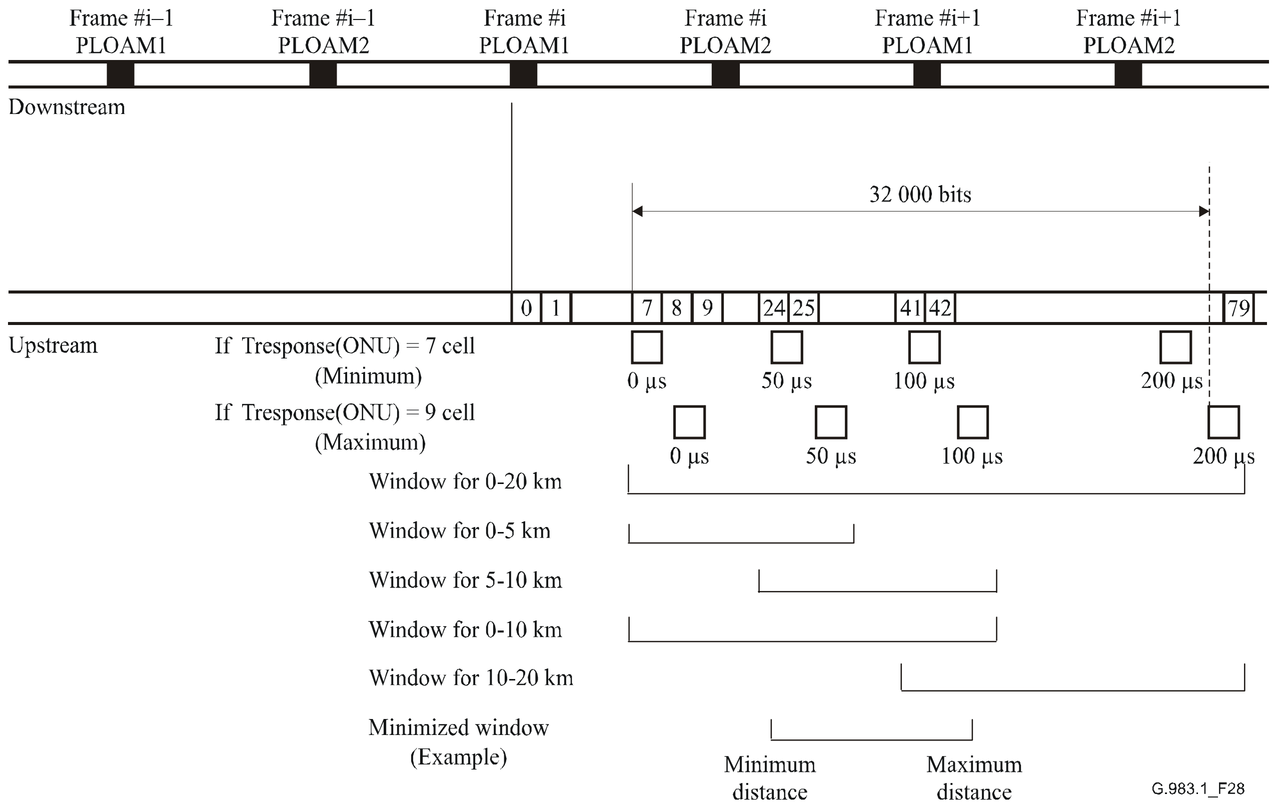
$$Td = Teqd - (T2 - T1)$$

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 28.



NOTE – Assuming the first grant of Frame #i is a ranging grant.

Figure 28/G.983.1 – Programmable ranging window (example)

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 29.

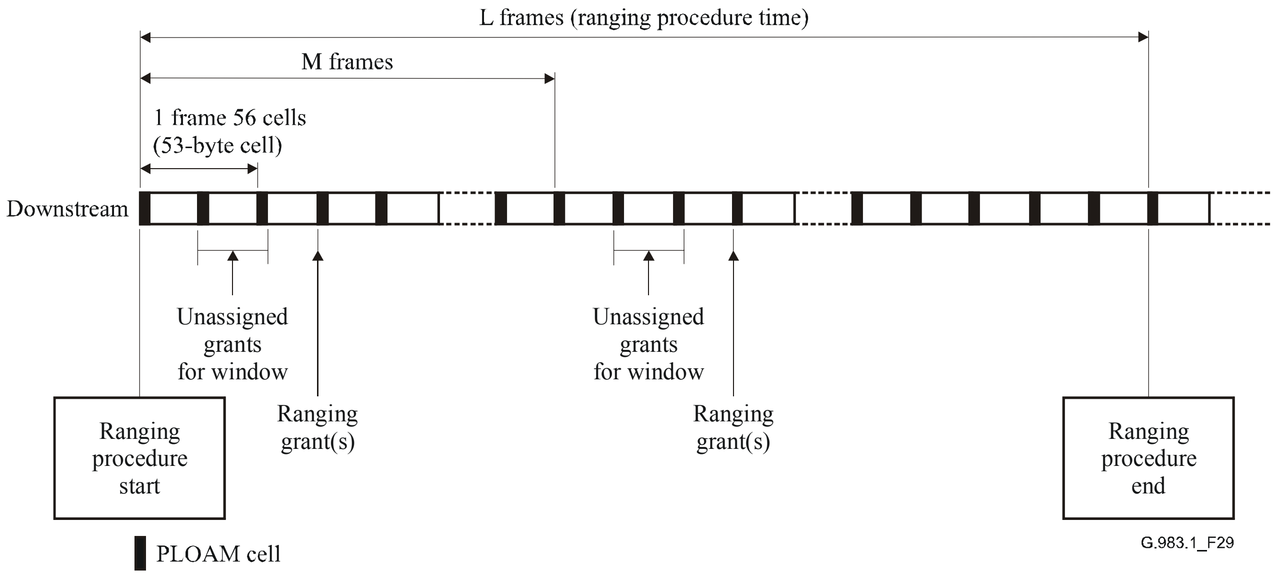


Figure 29/G.983.1 – Repeated opening of the ranging window

The value "M" in Figure 29 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.

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

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

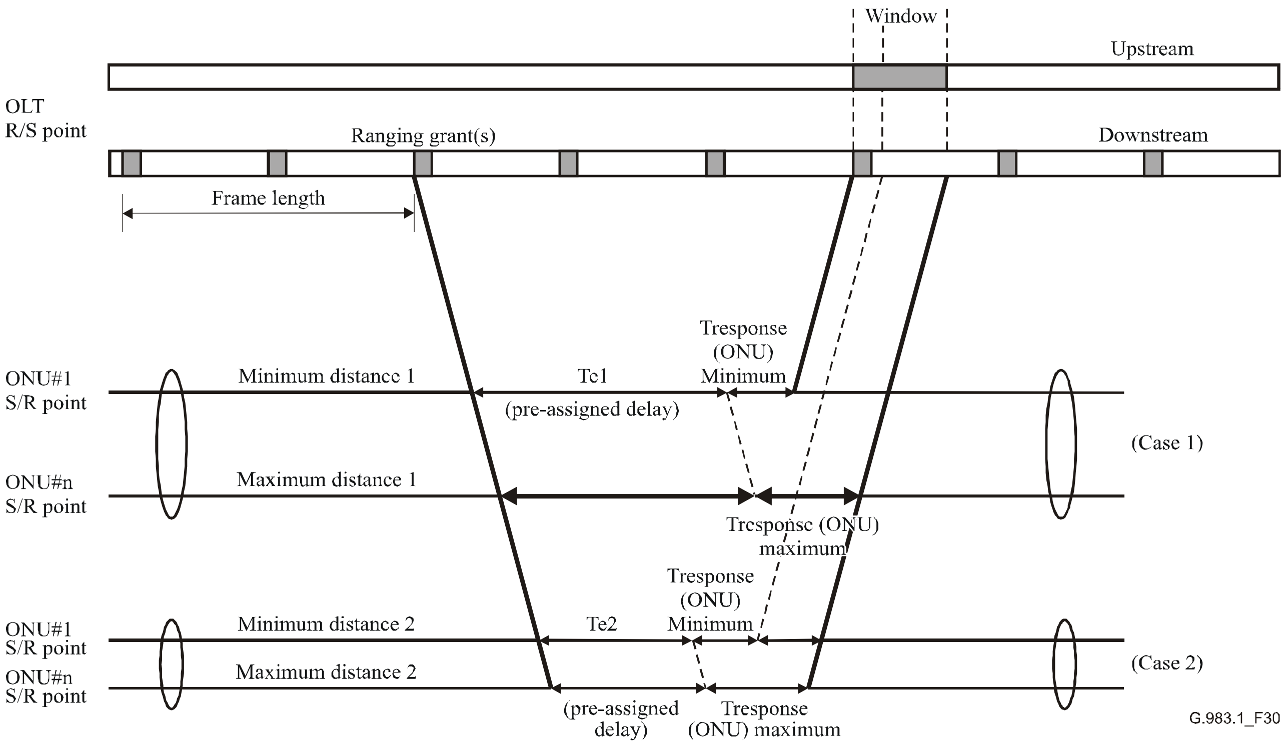


Figure 30/G.983.1 – Fixed location window with some knowledge about ONU locations

8.4.3 Definition of messages used in the ranging protocol

Messages used in the ranging protocol are defined in the TC layer specification section.

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.

8.4.4 Ranging procedure

8.4.4.1 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 some kind of grants and messages.

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 the 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.

8.4.4.2 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 III.1.

8.4.4.2.1 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 downstream messages are detectable. 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 of this state by any of the other events listed in Table 18 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.

8.4.4.2.2 Behaviour specification in the ONU

The state diagram in Table 18 is used for the description of the functional behaviour in the ONU. The first column in Table 18 indicates the generated events including message reception, and the first row indicates the states in the ONU.

Table 18/G.983.1 – The state diagram of the ONU

	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 [a)]	–	–	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? ⇒ 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	–	–	–	–

Table 18/G.983.1 – The state diagram of the ONU

	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 [a)]	match PON_ID? – timer TO1 stop ⇒ O2	match PON_ID? – timer TO1 stop ⇒ O2	match PON_ID? ⇒ O2	–	–

Table 18/G.983.1 – The state diagram of the ONU

	Operating standby state 2 (O6)	**Operating standby state 3 (O7)**	**Operating state (O8)**	**Emergency stop state 1 (O9)**	**POPUP state (O10)**
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	–	–	–	–	–

– 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.

– "–" means no action for corresponding event.

– PLOAM cell in the state of O6 or O7 should be transmitted with its Serial_number_ONU message with pre-assigned delay Te, and in the state of O4 should be transmitted in pre-assigned delay Te.

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

8.4.4.2.2.1 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) below, 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, the ONU acquires its PON_ID.

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 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 37^{th} 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 37^{th} 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 and then a transition to O7 occurs.

8.4.4.2.2.2 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.

8.4.4.2.2.3 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 standby 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.

8.4.4.3 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 III.2.

8.4.4.3.1 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.

8.4.4.3.2 Behaviour specification in the OLT

8.4.4.3.2.1 Common-part behaviour

The state diagram used for the description of the functional behaviour in the Common-part, is shown in Table 19. The first column of Table 19 indicates the generated events and the first row indicates the states in the Common-part.

Table 19/G.983.1 – 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	(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.		

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 nth Individual-ONU-dealing-part(n) is ready for its delay measurement.

d) Not-[Delay measurement condition complete(n)].

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. The 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.

e) SN acquisition request.

8.4.4.3.2.2 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 20. The first column of Table 20 indicates the generated events and the first row indicates the states in the Individual-ONU-dealing-part(n).

Table 20/G.983.1 – 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), LOAi(n), or R-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.			

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 is 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),) LOAi(n), or R-INHi(n)*

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

8.4.4.3.3 Procedure for the equalization_delay

The equalization_delay (Td) shall be defined as described in 8.4.2.3. 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; 79 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.

8.4.4.3.4 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.

8.4.5 Ranging time requirements

The ranging time should be satisfied as in Table 21.

Table 21/G.983.1 – Ranging time requirements

Item	PON condition (Note 1)	ONU condition (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 (Note 2)	warm	warm	A	16	100 ms
7 (Note 3)	switchover	warm	Refer to 8.3.9.		

NOTE 1 – For explanation of the PON and ONU conditions, see 8.4.1.2.

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 8.4.1.1, 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 must be completed within the time stated in 8.3.9.

8.4.6 Conventional ranging sequence

The diagram shown in Figure 31 illustrates the normal exchange of messages between the OLT and ONU during the ranging process.

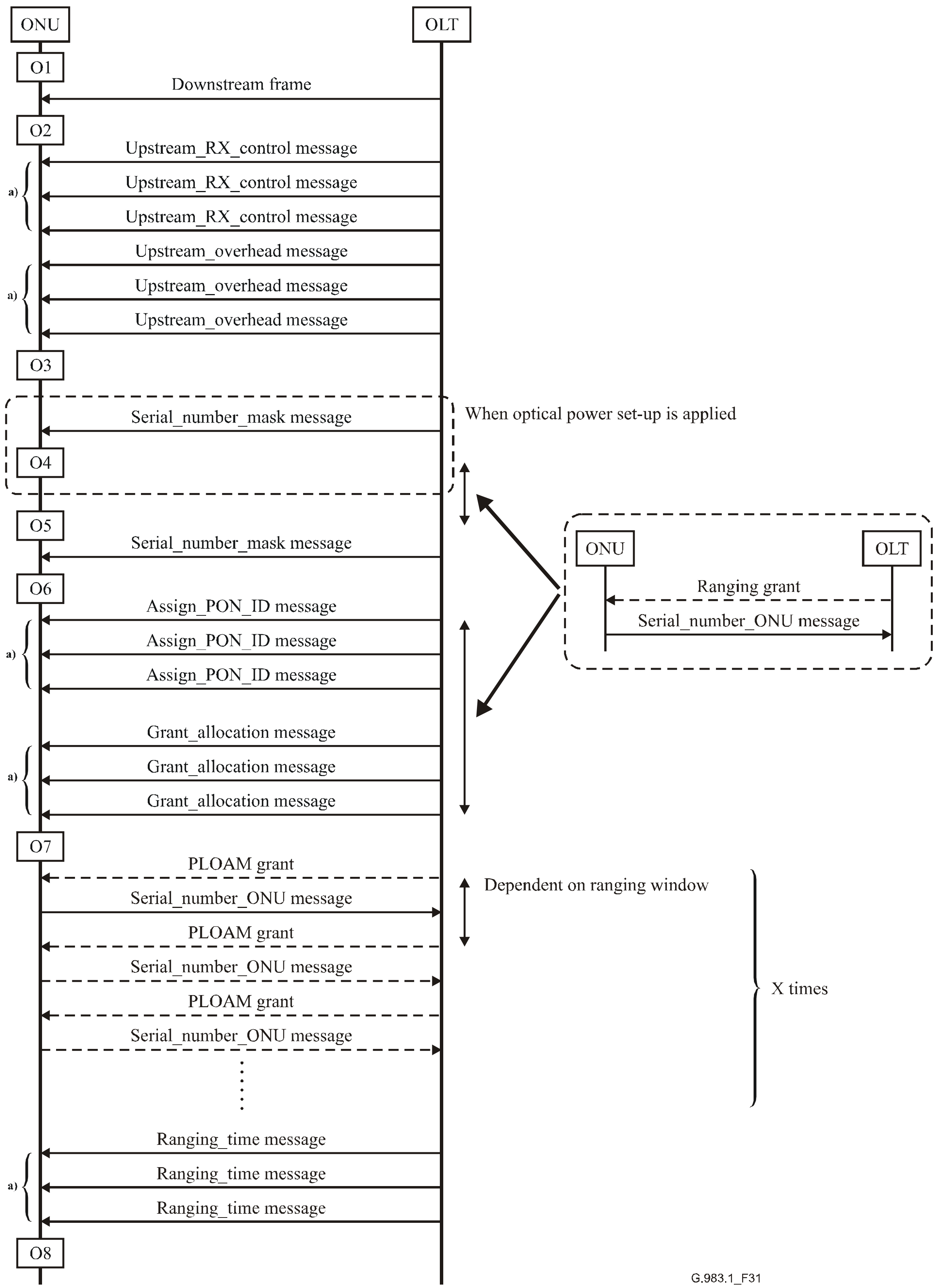


Figure 31/G.983.1 – Message sequence for ranging

Notes to Figure 31

NOTE 1 – It is specified that the processing time for each PLOAM message in ONU is within 6 T frame (6*Tframe). ONU can receive PLOAM messages from OLT at any interval.

NOTE 2 – There are two ways to complete Optical power set-up. One is that ONU in O3 completes Optical power set-up by itself, and the other is that ONU in O4 receives some ranging grants and sends some upstream PLOAM cells. In the latter case, OLT must know beforehand the number of times and timing of sending ranging grants. These values are related to the ranging time and the number of ranging windows. Therefore the way to complete Optical power set-up should be selected by operators according to their service requirements.

NOTE 3 – In O4 and O6, if OLT gives Ranging grants to ONU, ONU has to send Serial_number_ONU message to OLT.

NOTE 4 – ONU can move to the next action, when it receives one message at least in 3 consecutive messages indicated by ([a]). The detailed operations are as follows:

- ONU can move to O3 from O2 when it receives one Upstream_overhead message at least.
- ONU can receive Grant_allocation messages when it receives one Assigned_PON_ID message at least.
- ONU can move to O7 from O6 when it receives one Grant_allocation message at least.
- ONU can move to O8 from O7 when it receives one Ranging_time message at least.

NOTE 5 – If an OLT is going to utilize the Rx control field, the OLT will send the Upstream_RX_control message before it tries to use that facility.

NOTE 6 – Serial_number_ONU messages are sent from ONU according to PLOAM grants in O7 *X* times. *X* is specified by OLT implementation.

9 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 subsystems 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 Rec. M.3010:

a) configuration management;
b) performance management;
c) fault management;
d) security management;
e) accounting management: out of scope.

Refer to Appendix III/G.982 for further information.

10 Performance

Mean signal transfer delay time between T-V (or a-V) should be less than 1.5 ms as defined in ITU-T Rec. G.982. 1.5 ms is a guideline for telephony service.

ATM cell delay variation at the ATM layer is defined by ATM performance, (ITU-T Rec. I.356).

11 Environmental condition

The conditions of IEC 60721-3-3 is recommended.

The conditions of IEC 60801-2 and 60801-3 for electromagnetic compatibility are recommended.

Examples of applied environmental conditions of temperature and relative humidity for OLT and ONU are described in Table 22. The other environmental conditions such as environmental pollutants and chemicals are for further study.

Table 22/G.983.1 – Examples of environmental conditions

Applied example	Temperature (C)		Relative humidity (%)		Remarks
	Normal	Short term	Normal	Short term	
OLT	5 to 40	0 to 50 (Note)	5 to 85	5 to 90 (Note)	IEC 60721-3-3 class 3k3
Indoor ONU	–5 to 45	–	5 to 95	–	IEC 60721-3-3 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 four days in one year.					

12 Safety

12.1 Electrical safety and protection

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

12.2 Optical safety and protection

The ONU transmitter optical power levels shall not exceed Class 1 as defined in IEC 60825-1 (1993).

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.

Appendix I

Optional cases of overall minimum ORL of ODN at O_{ru} and O_{rd}, and O_{ld} and O_{lu}

I.1 Introduction

In 8.2.7.2, the minimum ORL of ODN at O_{ru} and O_{rd}, and O_{ld} and O_{lu} is specified better than 32 dB. This appendix describes example cases for the ORL that becomes less than 32 dB.

I.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 I.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 −14 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 −(−14 – 6) = 20 dB.

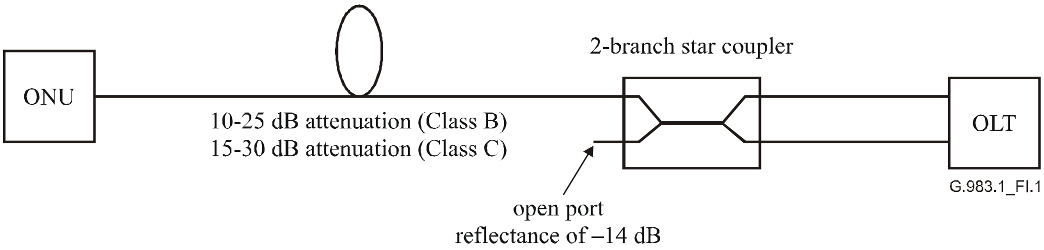


Figure I.1/G.983.1 – Effect of open connectors located at ONU side of star coupler

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

As shown in Figure I.2, when one port is not terminated at the 2-branch star coupler, subject that the reflectance of the port is −14 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 −(−14 – 6) = 20 dB.

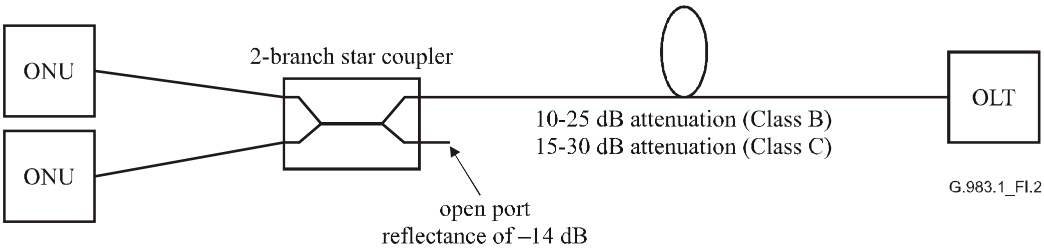


Figure I.2/G.983.1 – Effect of open connectors located at OLT side of star coupler

Especially in the case of FTTH, many connectors are allocated near the ONU. In this case, this 20 dB corresponds to a reflection of 4 PC connectors whose reflectance is −25 dB for each connector.

I.4 Effect of disconnecting a connector near ONU

NOTE – In Figure I.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 ONU-A. This "double reflected" signal may overlap a burst signal from ONU-B. Figure I.4 shows the overlap of signal.

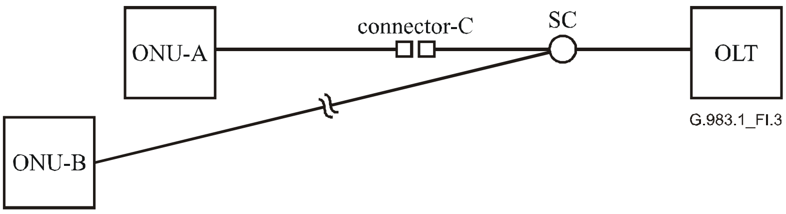
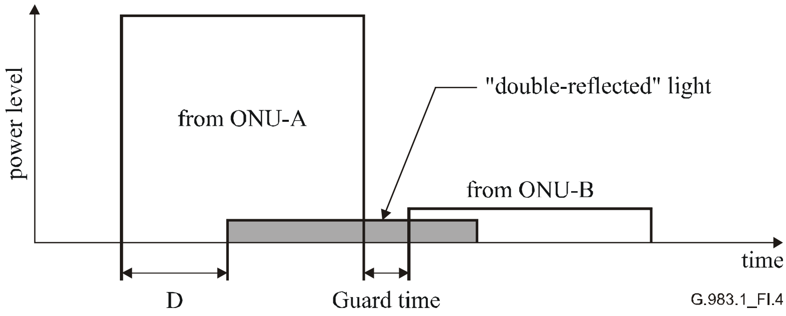


Figure I.3/G.983.1 – Effect of disconnecting a connector near ONU



D Round-trip time between ONU-A and connector-C.

Figure I.4/G.983.1 – Overlap of burst signal and reflected light

Appendix II

Effect of optical return loss of ODN

II.1 Introduction

Each network model has its own optical return loss (ORL) of ODN and PON is sensitive to the ORL of ODN. This appendix 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 20 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.

II.2 ODN optical return loss of 32 dB

II.2.1 Reflectance model to be considered

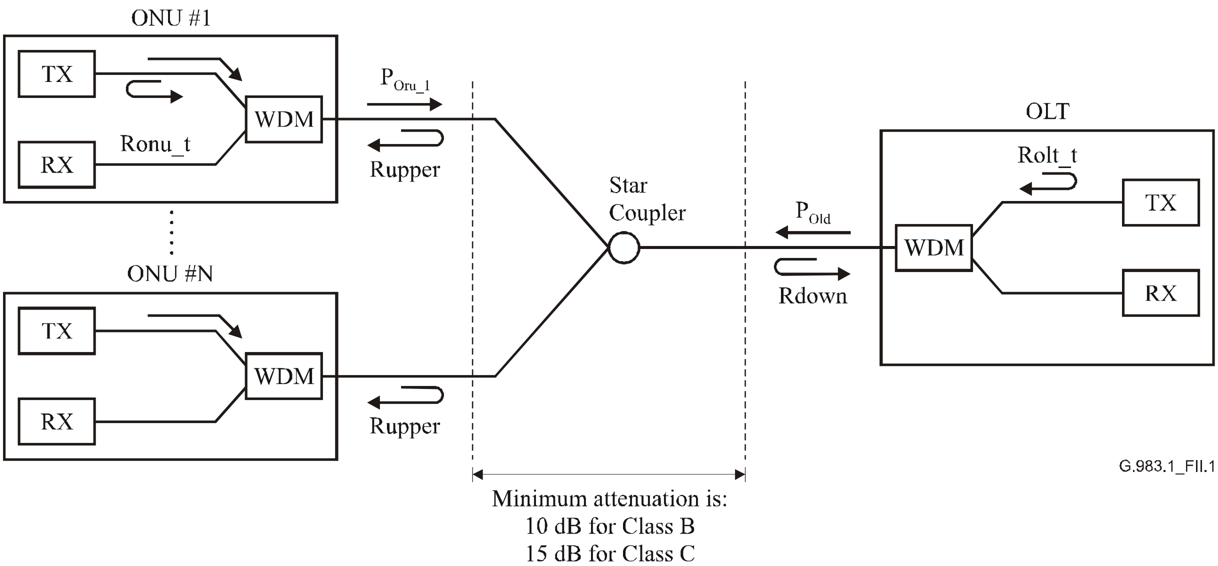


Figure II.1/G.983.1 – Reflectance model to be considered

The following notations are used in this appendix:

P_{Oru_n}	Optical output power of ONU #n transmitter at O_{ru}
P_{Old}	Optical output power of OLT transmitter at O_{ld}
Ronu_t	ONU transmitter equipment reflectance
Rolt_t	OLT transmitter equipment reflectance
Rupper	ORL of ODN at O_{ru} and O_{rd}
Rdown	ORL of ODN at O_{ld} and O_{lu}
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 appendix.

II.2.2 Influence of reflectance into ONU receiver

Figure II.2 shows the path of reflected signal to be considered. Equation A must be satisfied:

$$P_{Oru\_1} - Rupper - Ionu\_r \text{ (permissible interference optical power)} \qquad \text{(Equation A)}$$

In Figure II.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:

$$+2 - 32 - Ionu\_r < -40 \qquad \text{(II-1)}$$

We obtain:

$$Ionu\_r > 10 \text{ dB} \qquad \text{(II-2)}$$

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:

$$+4 - 32 - Ionu\_r < -43 \qquad \text{(II-3)}$$

We obtain:

$$Ionu\_r > 15 \text{ dB} \qquad \text{(II-4)}$$

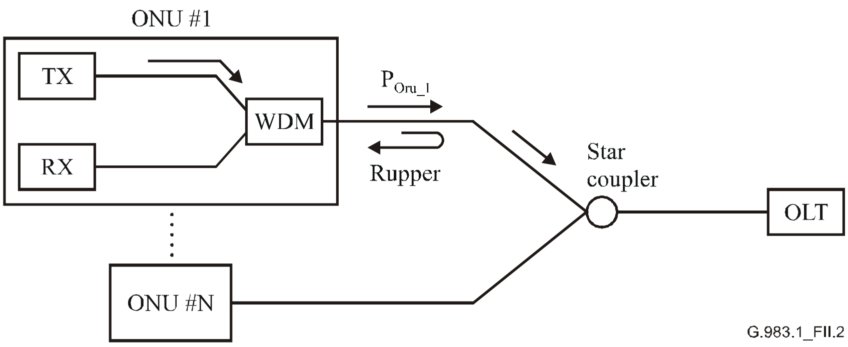


Figure II.2/G.983.1 – Model for incidence into ONU receiver

II.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.

II.2.3.1 Case 1

Figure II.3 shows the path of reflectance signals. Equation B must be satisfied:

$$\text{(maximum differential of bursted signal optical levels)} - Rupper - Ronu\_t < \text{(permissible interference optical power ratio)} \qquad \text{(Equation B)}$$

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

$$(15+6) - 32 - Ronu\_t < -10 \qquad \text{(II-5)}$$

then:

$$Ronu\_4 > -1\ dB \qquad \text{(II-6)}$$

Therefore, requirement for Ronu_t in this case is not necessary.

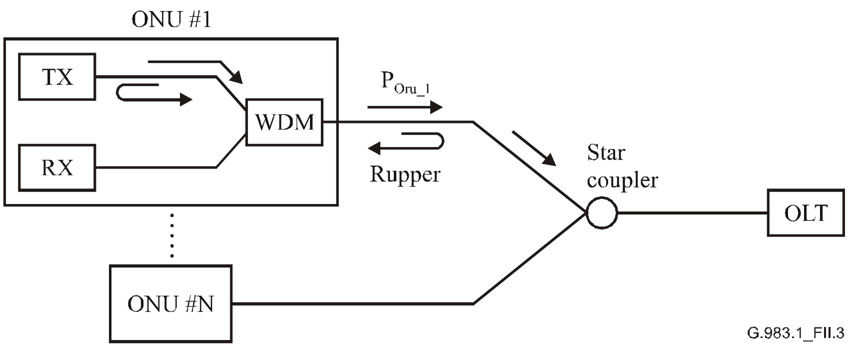


Figure II.3/G.983.1 – Model 1 for incidence into OLT receiver

II.2.3.2 Case 2

Figure II.4 shows the path of reflectance signals. Equation C must be satisfied:

$$\text{(maximum differential of burst signal optical level)} - Rolt\_t - Rdown - Iolt\_t \times 2 < \text{(permissible interference optical power)} \qquad \text{(Equation C)}$$

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

$$(15+6) - Rolt\_t - 32 - Iolt\_t \times 2 < -10 \qquad \text{(II-7)}$$

then:

$$Rolt\_t + Iolt\_t \times 2 > -1\ \text{dB} \qquad \text{(II-8)}$$

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

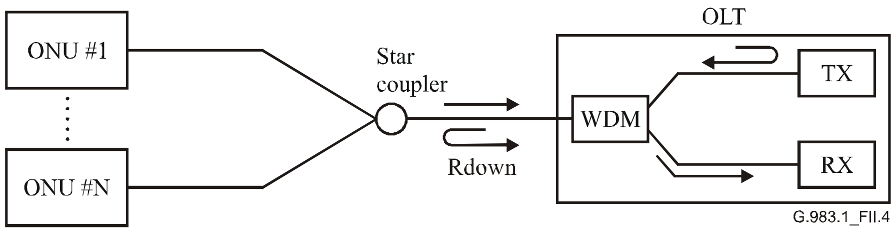


Figure II.4/G.983.1 – Model 2 incidence into OLT receiver

II.2.3.3 Case 3

Figure II.5 shows the path of reflectance signals. Equation D must be satisfied:

$$P_{Old} - Rdown - Iolt\_r < \text{(permissible interference optical power)} \qquad \text{(Equation D)}$$

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:

$$+2 - 32 - Iolt\_r < -40 \qquad \text{(II-9)}$$

We obtain:

$$Iolt\_r > 10 \text{ dB} \qquad \text{(II-10)}$$

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:

$$+4 - 32 - Iolt\_r < -43 \qquad \text{(II-11)}$$

We obtain:

$$Iolt\_r > 15 \text{ dB} \qquad \text{(II-12)}$$

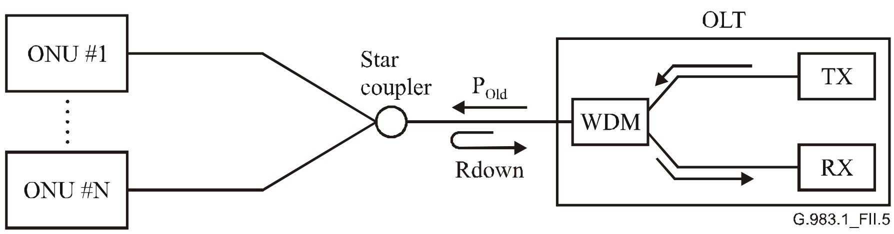


Figure II.5/G.983.1 – Model 3 for incidence into OLT receiver

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

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

II.2.4.1 Case 1

Figure II.3 shows the path of reflectance signals. Equation E must be satisfied:

$$P_{Oru\_1} - Rupper - Ronu\_t - \text{(minimum optical path attenuation)} < \text{(determination level as no signal)} \qquad \text{(Equation E)}$$

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:

$$+2-32-Ronu\_t-10<-40 \tag{II-13}$$

We obtain:

$$Ronu\_t>0 \text{ dB} \tag{II-14}$$

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:

$$+4-32Ronu\_t-15<-43 \tag{II-15}$$

We obtain:

$$Ronu\_t>0 \text{ dB} \tag{II-16}$$

Therefore, requirement for Ronu_t in this case is not necessary.

II.2.4.2 Case 2

Figure II.5 shows the path of reflectance signals. Equation F must be satisfied:

$$P_{Old}-Rdown-Iolt\_r< \text{(determination level as no signal)} \tag{Equation F}$$

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:

$$+2-32-Iolr\_r<-40 \tag{II-17}$$

We obtain:

$$Iolt\_r>10 \text{ dB} \tag{II-18}$$

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:

$$+4-32-Iolt\_r<-43 \tag{II-19}$$

We obtain:

$$Iolr\_r>15 \text{ dB} \tag{II-20}$$

II.3 Other case of ODN reflectance

The calculation method mentioned above is available for the case that ODN reflectance is –20 dB. Table II.1 shows the requirement for optical parameters when minimum ORL of ODN is 32 dB and 20 dB.

WDM isolation parameter is an implementation matter, and values concerning WDM isolation parameters in the Table II.1 are just informative. This appendix 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 must 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 20 dB, ONU transmitter equipment reflectance must be less than 12 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 the case that ORL of ODN is 32 dB and 20 dB, values of equipment reflectance for ONU transmitter in Table II.1 are applicable. In the other case, the appropriate value is derived by means of the calculation method mentioned above.

Table II.1/G.983.1 – Values for ONU transmitter equipment reflectance

Min ORL of ODN	Class	Optical parameters	Required characteristics					
			A[a)]	B[a)]	C[a)]	D[a)]	E[a)]	F[a)]
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	
20 dB	B	WDM isolation for ONU receiver	22 dB					
		WDM isolation for ONU transmitter						
		WDM isolation for OLT receiver				22 dB		22 dB
		WDM isolation for OLT transmitter			2.5 dB			
		Equipment reflectance for ONU transmitter		11 dB			12 dB	
	C	WDM isolation for ONU receiver	27 dB					
		WDM isolation for ONU transmitter						
		WDM isolation for OLT receiver				27 dB		27 dB
		WDM isolation for OLT transmitter			2.5 dB			
		Equipment reflectance for ONU transmitter		11 dB			12 dB	

a) A, B, C, D, E and F represent Equation A, Equation B, Equation C, Equation D, Equation E and Equation F, respectively.

Appendix III

Ranging flow diagrams

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.

III.1 Ranging flow in the ONU (example)

Figure III.1 (sheets 1 to 7 of 7) indicate an example ranging flow in the ONU. It is not intended to specify the ranging procedure and is only shown for information.

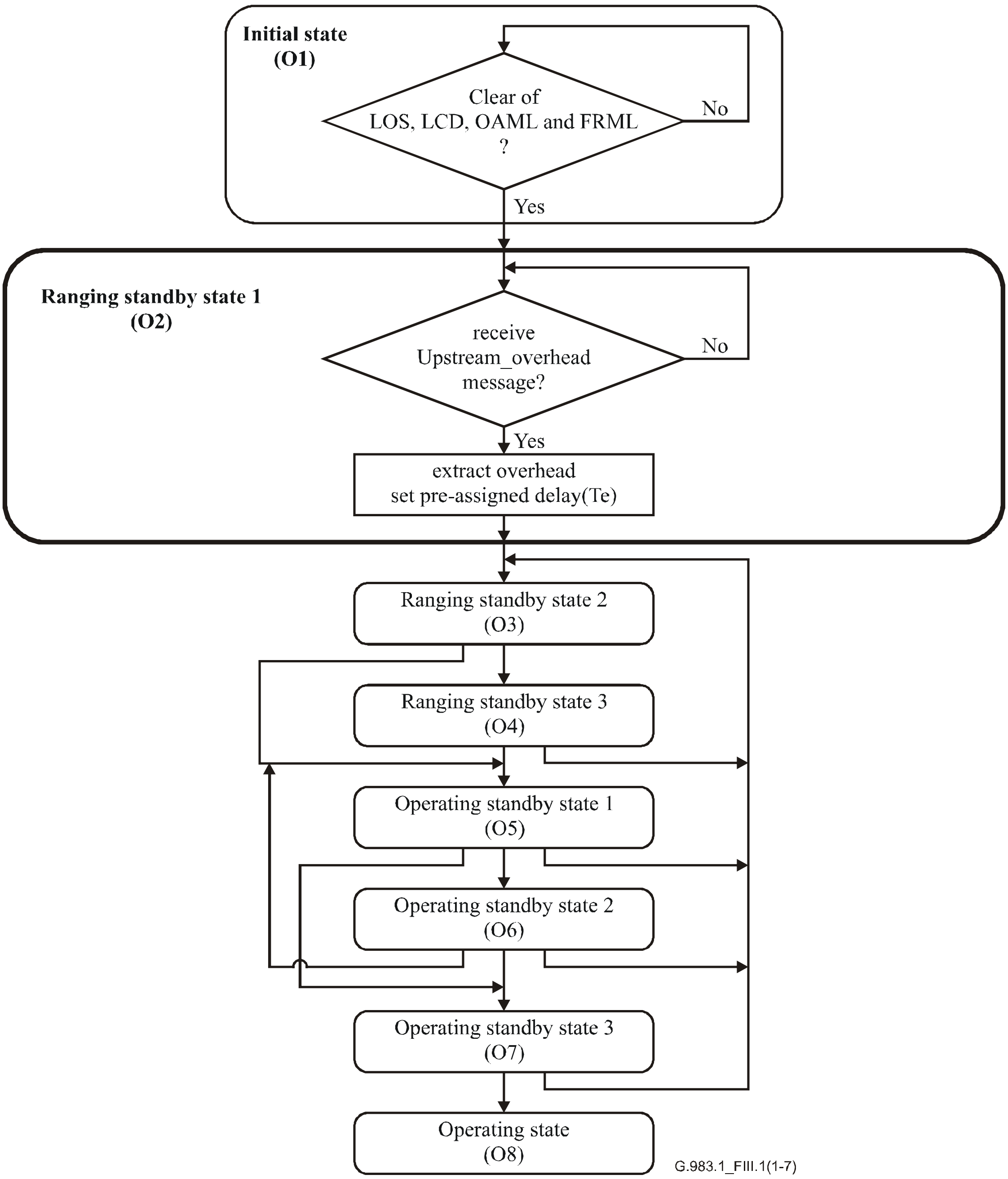


Figure III.1/G.983.1 – Ranging flow [ONU] (example) ***(sheet 1 of 7)***

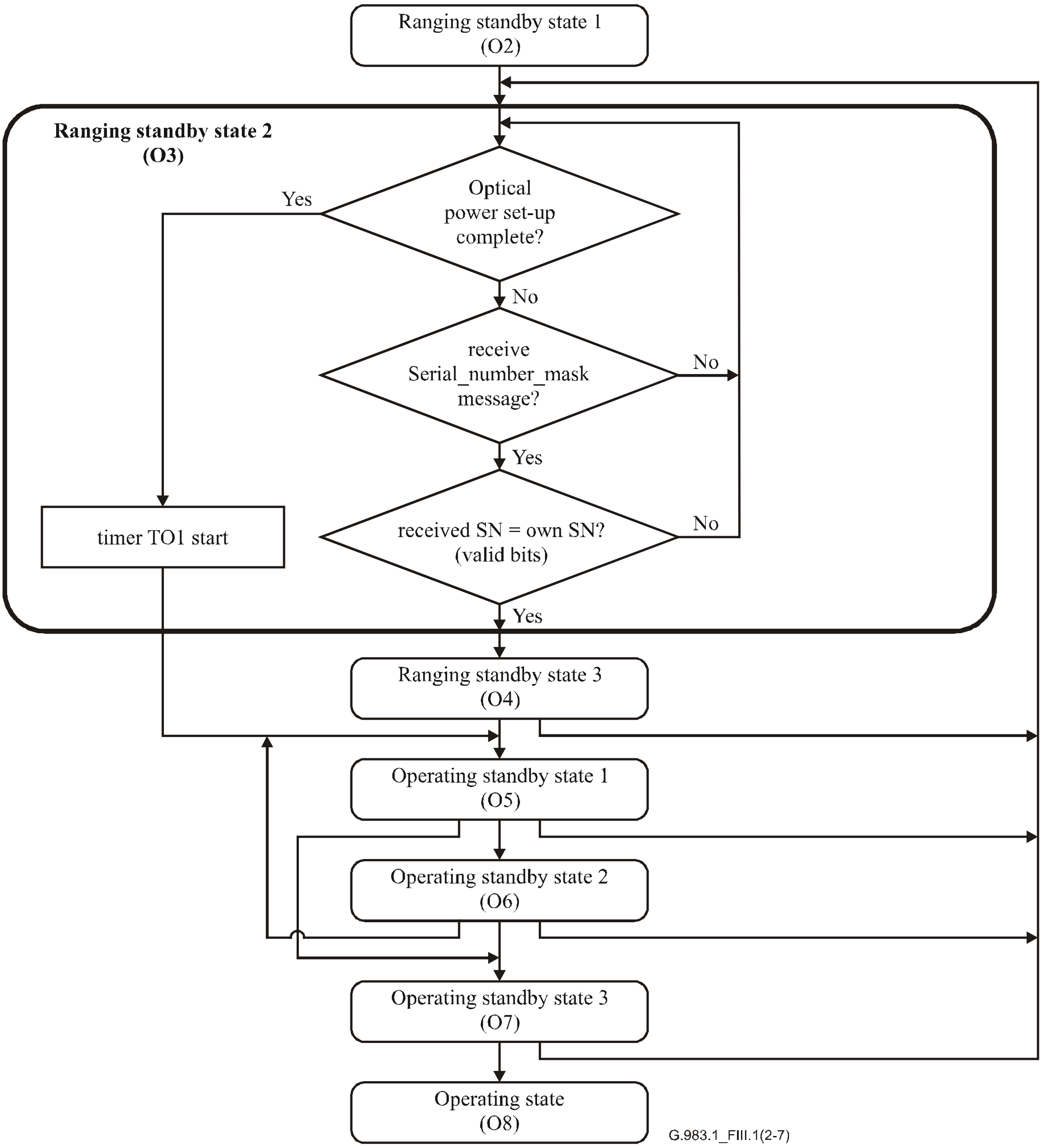


Figure III.1/G.983.1 – Ranging flow [ONU] (example) ***(sheet 2 of 7)***

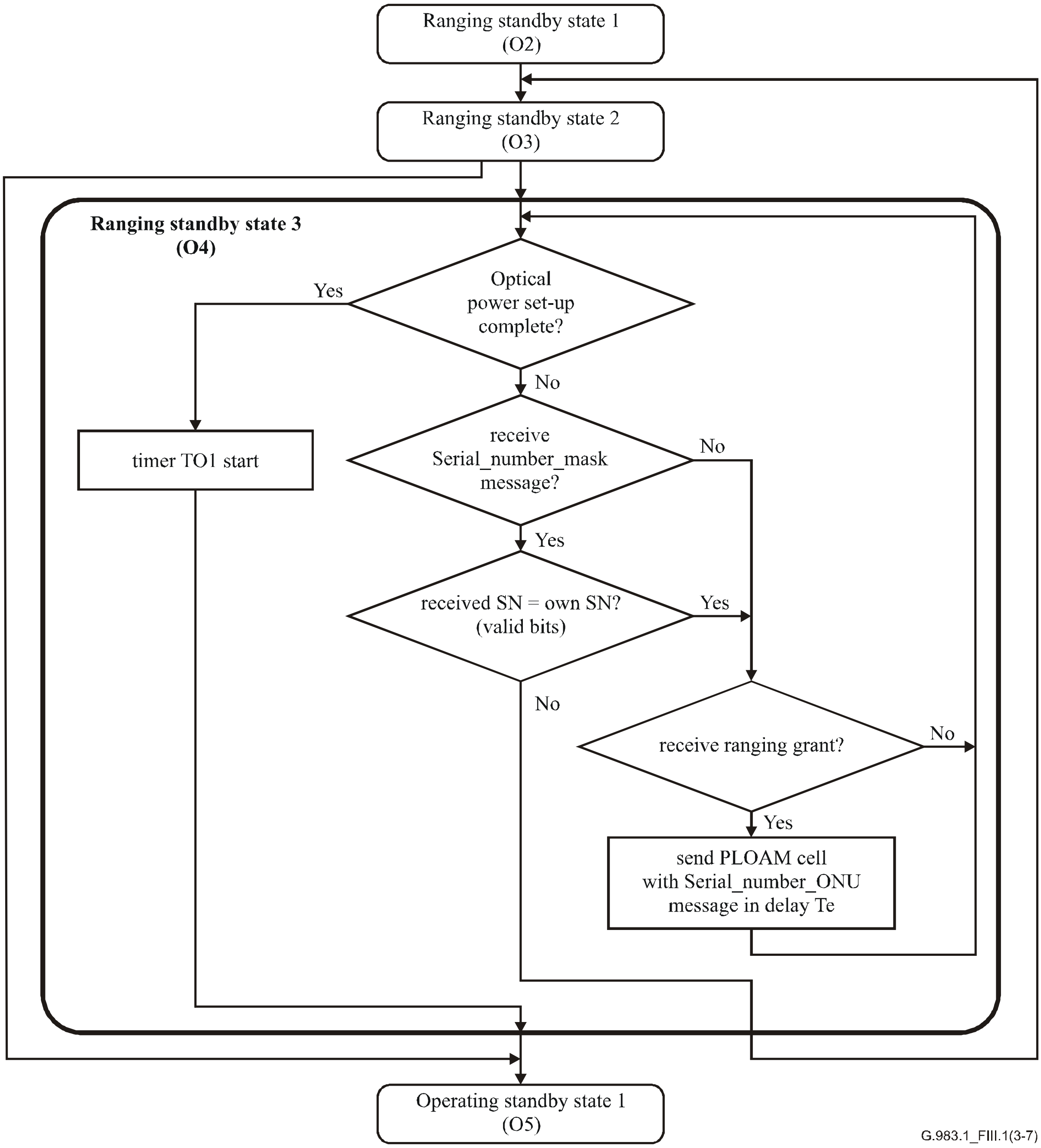


Figure III.1/G.983.1 – Ranging flow [ONU] (example) ***(sheet 3 of 7)***

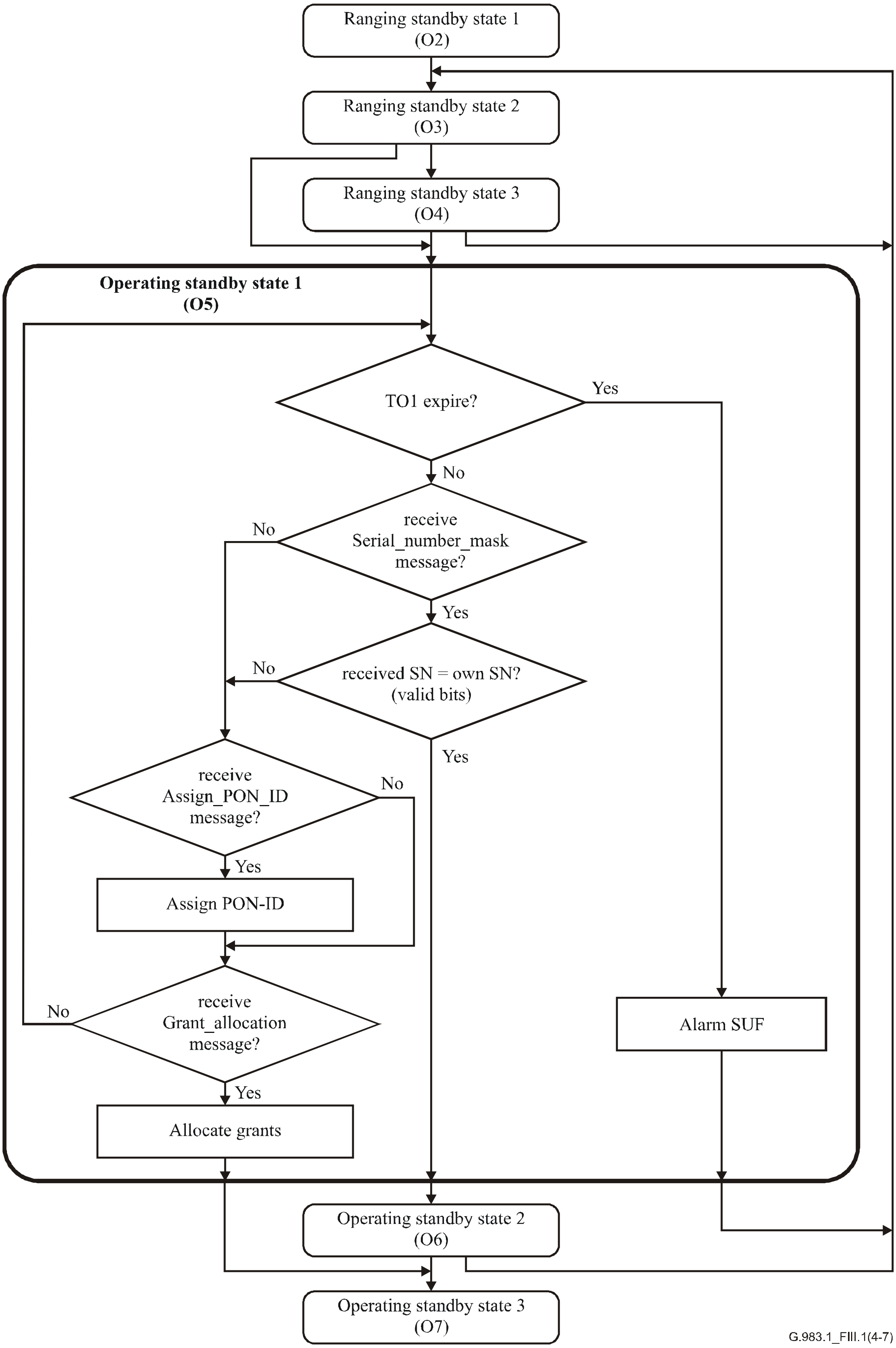


Figure III.1/G.983.1 – Ranging flow [ONU] (example) ***(sheet 4 of 7)***

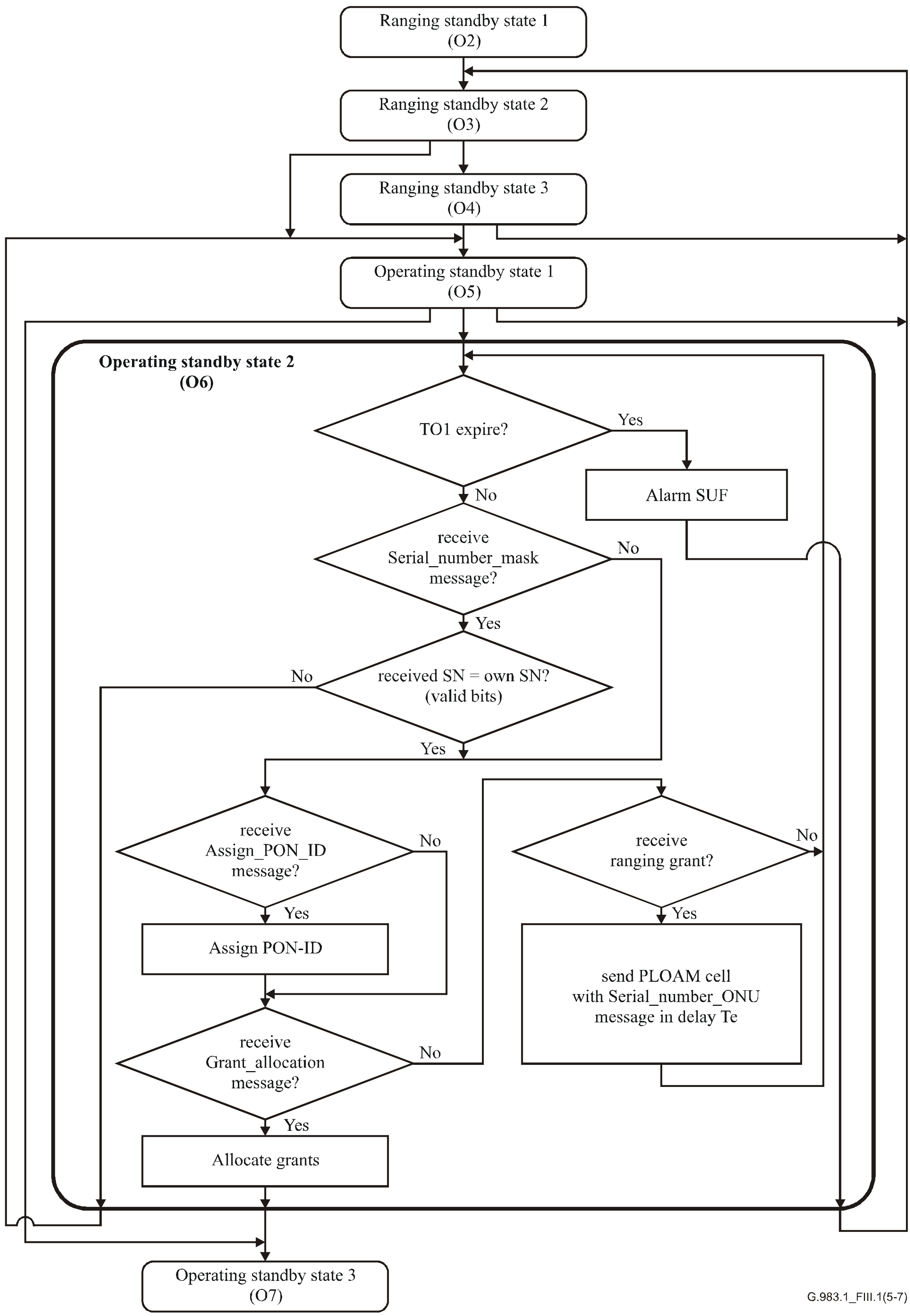


Figure III.1/G.983.1 – Ranging flow [ONU] (example) ***(sheet 5 of 7)***

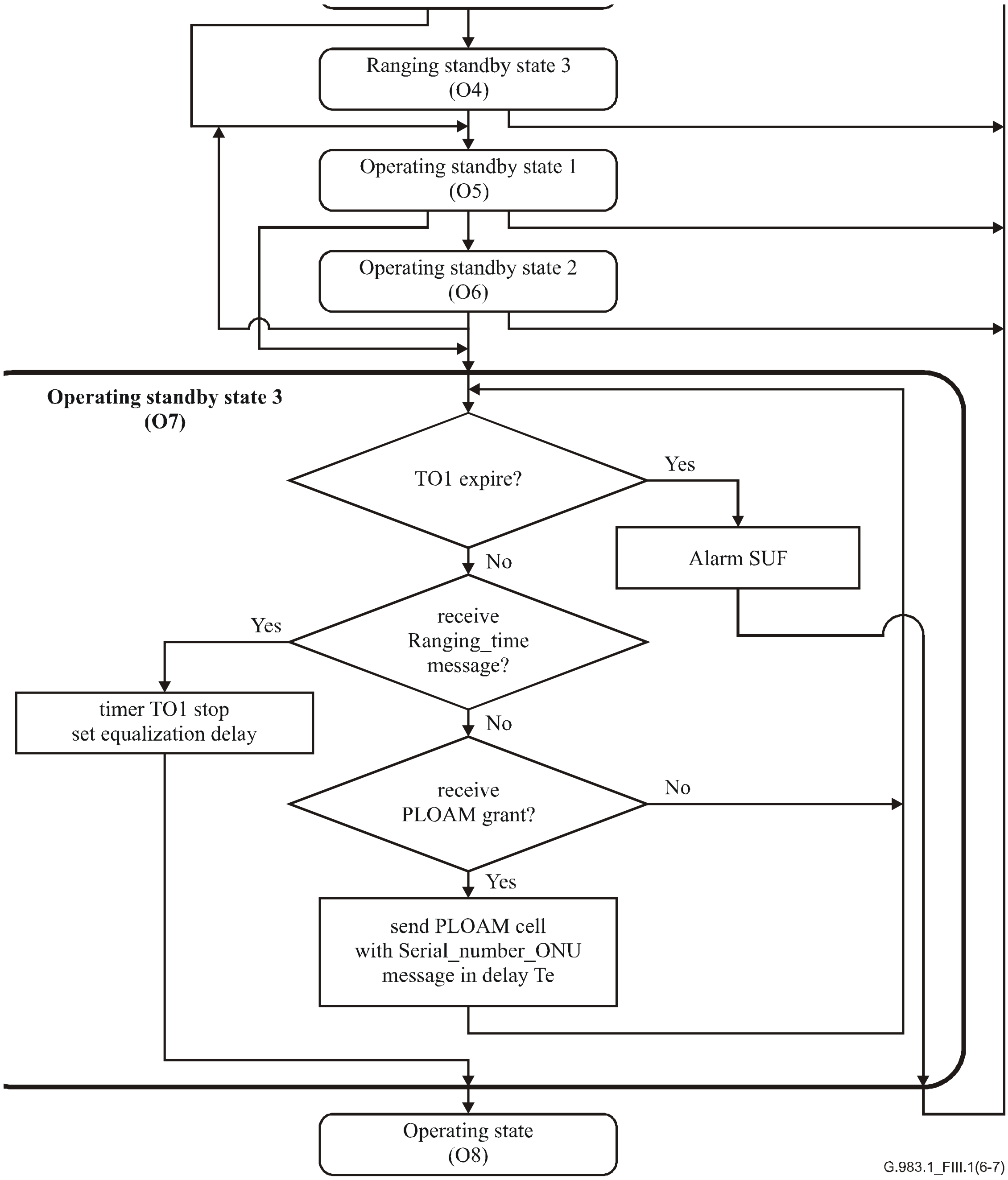


Figure III.1/G.983.1 – Ranging flow [ONU] (example) ***(sheet 6 of 7)***

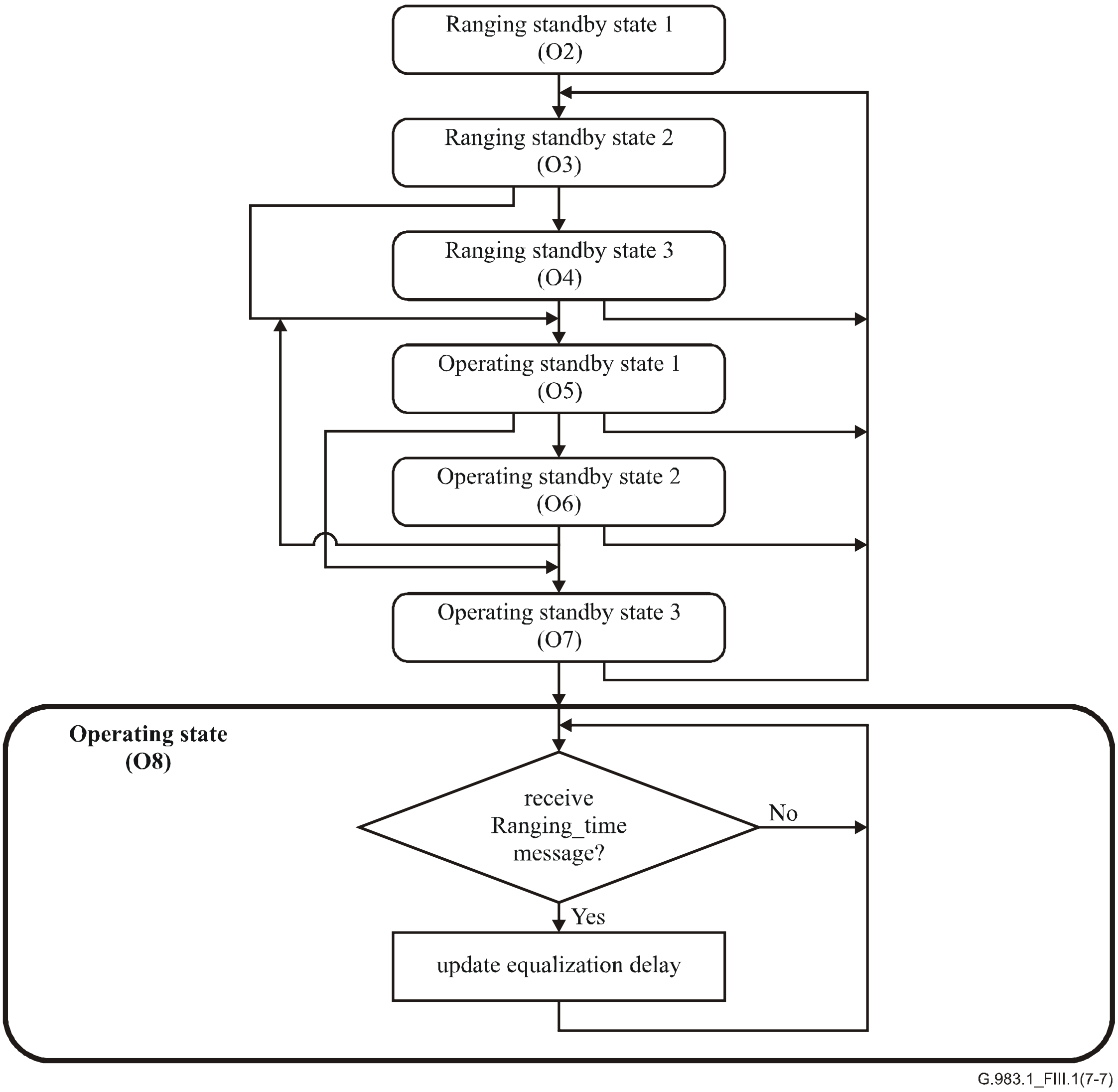


Figure III.1/G.983.1 – Ranging flow [ONU] (example) ***(sheet 7 of 7)***

III.2 Ranging flow in the OLT (example)

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

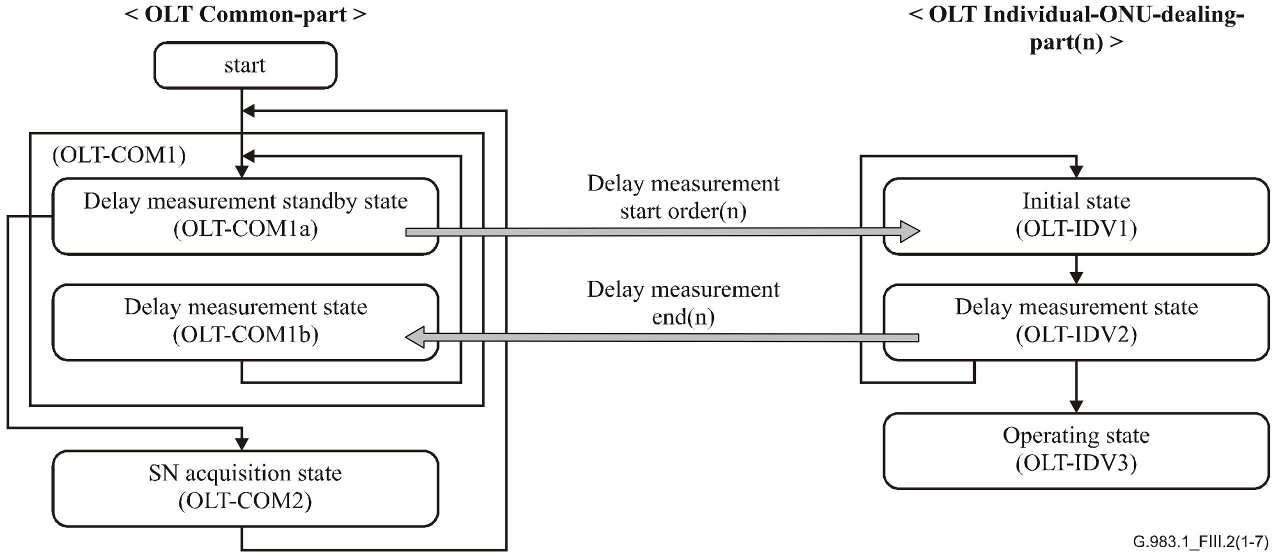


Figure III.2/G.983.1 – Ranging flow [OLT] (example) ***(sheet 1 of 7)***

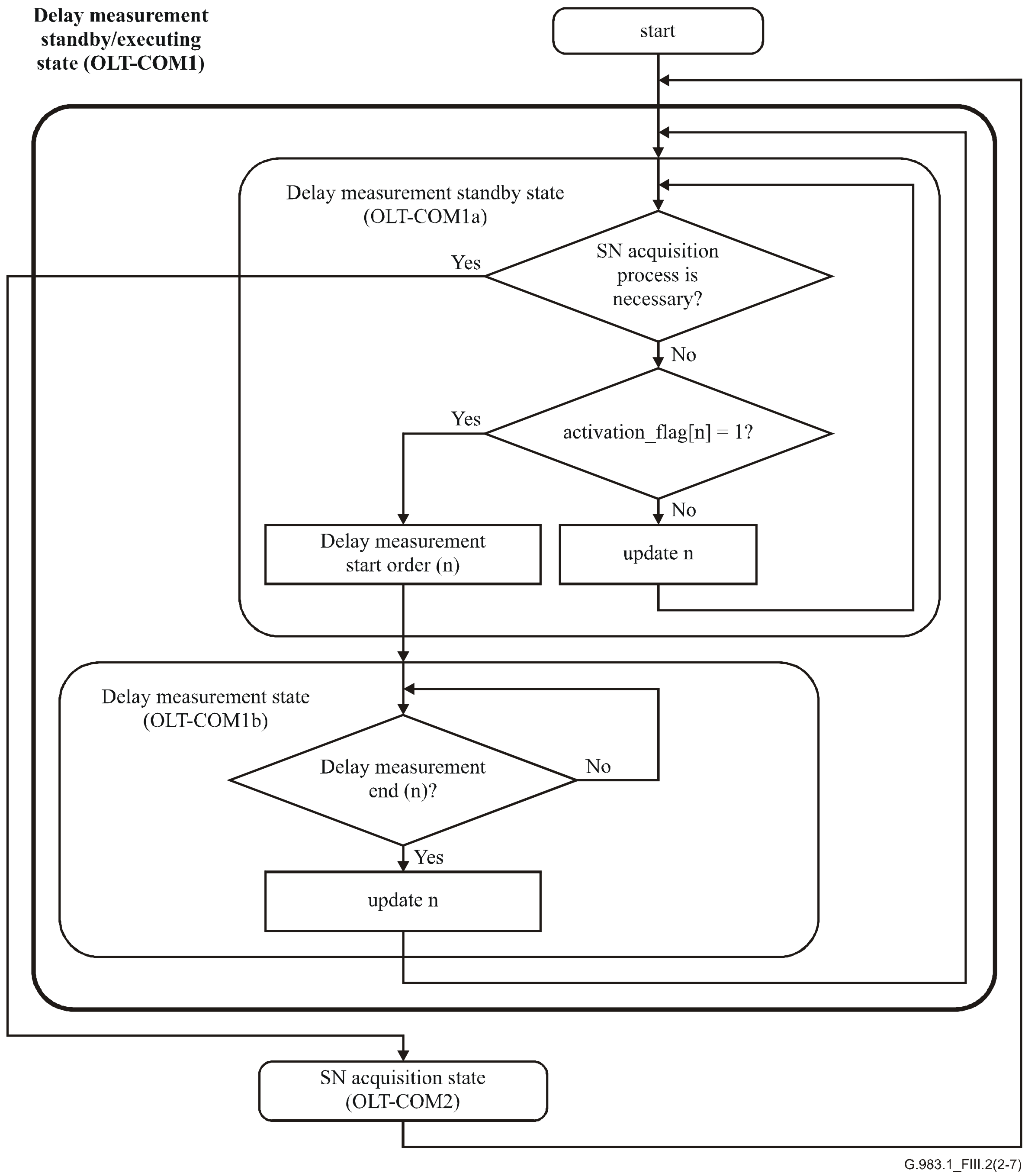


Figure III.2/G.983.1 – Ranging flow [OLT] (example) ***(sheet 2 of 7)***

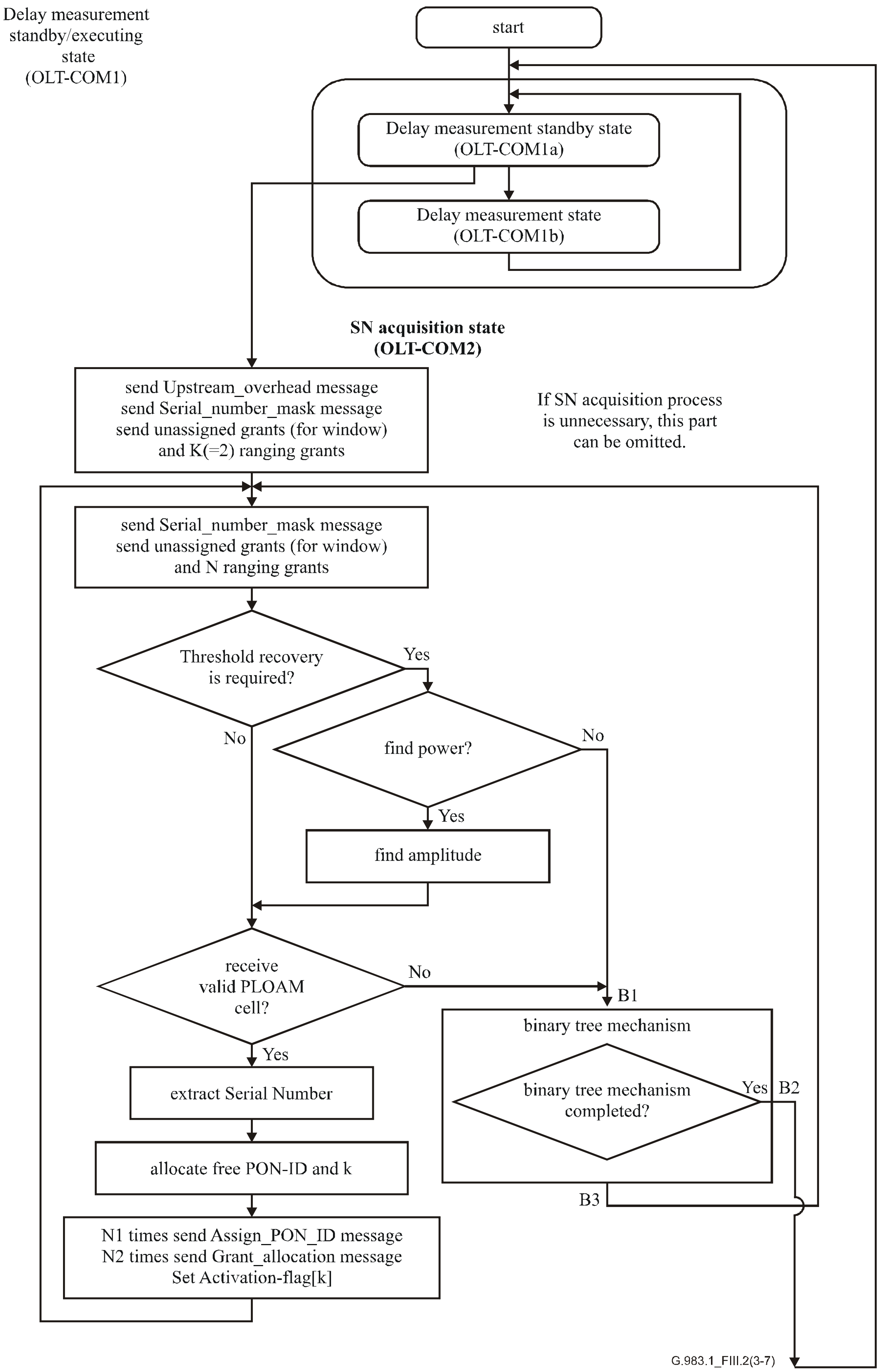
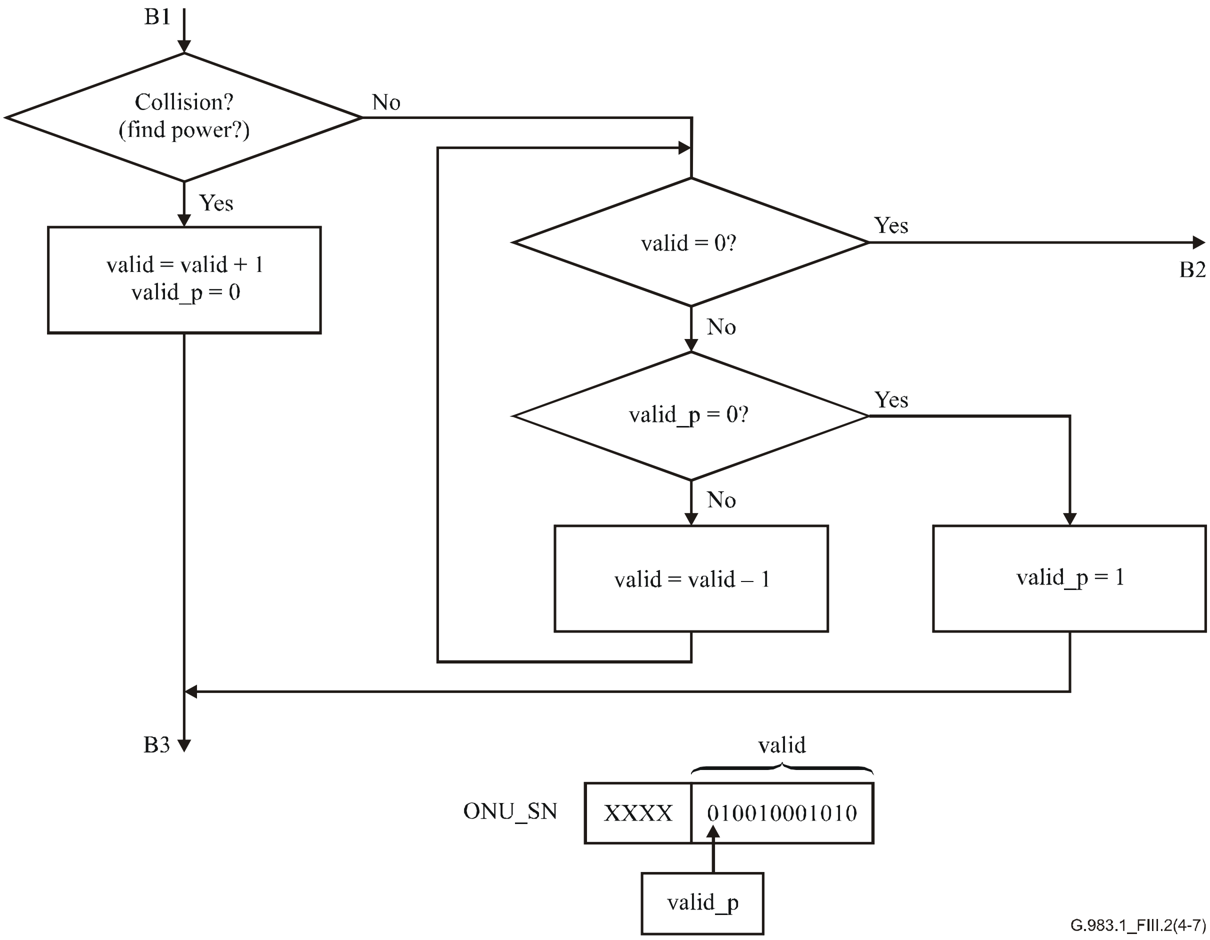


Figure III.2/G.983.1 – Ranging flow [OLT] (example) *(sheet 3 of 7)*



NOTE – The points of B1, B2 and B3 correspond to the points of B1, B2 and B3 in Figure III.2 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 III.2/G.983.1 – Ranging flow [OLT] (example) *(sheet 4 of 7)*

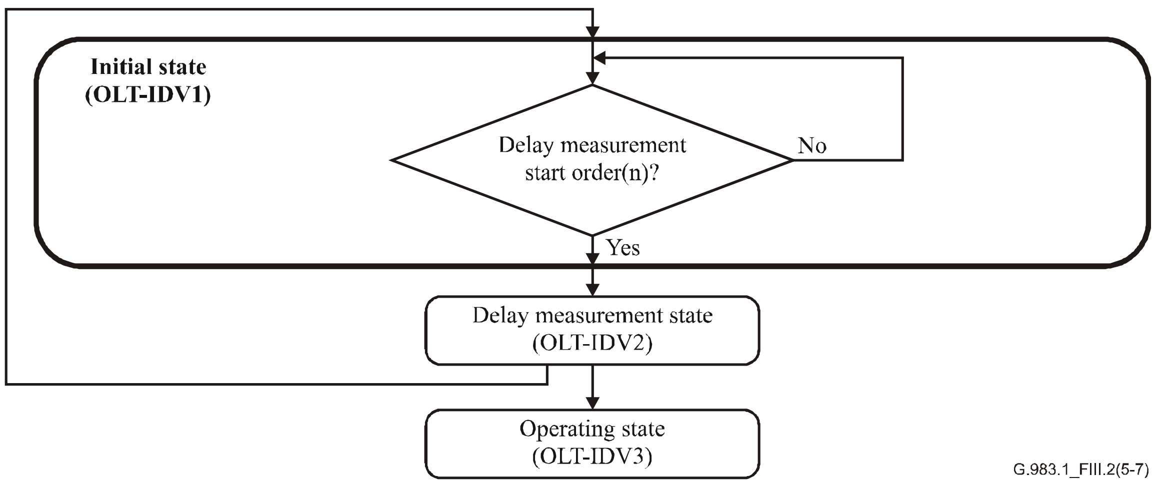


Figure III.2/G.983.1 – Ranging flow [OLT] (example) *(sheet 5 of 7)*

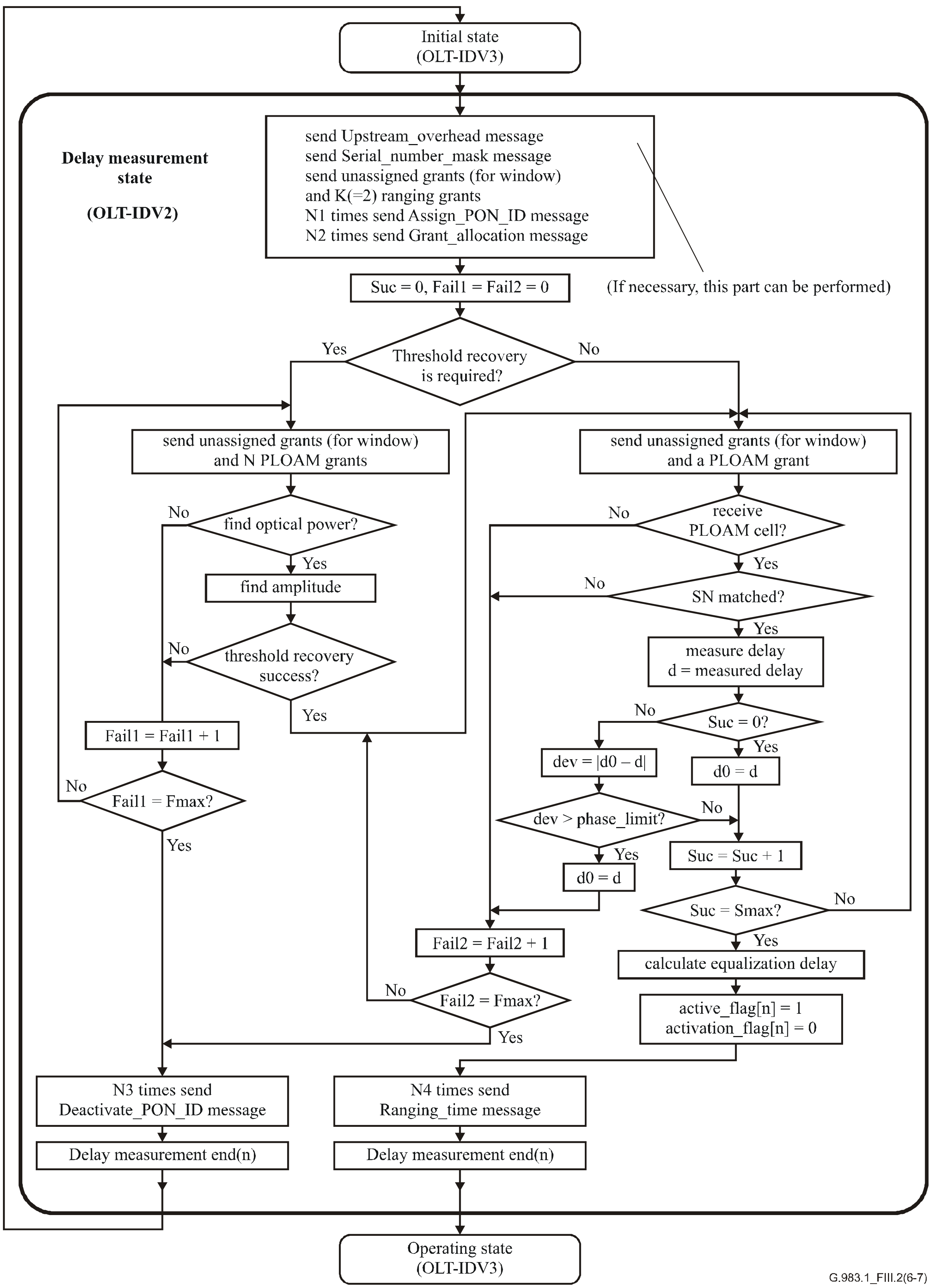
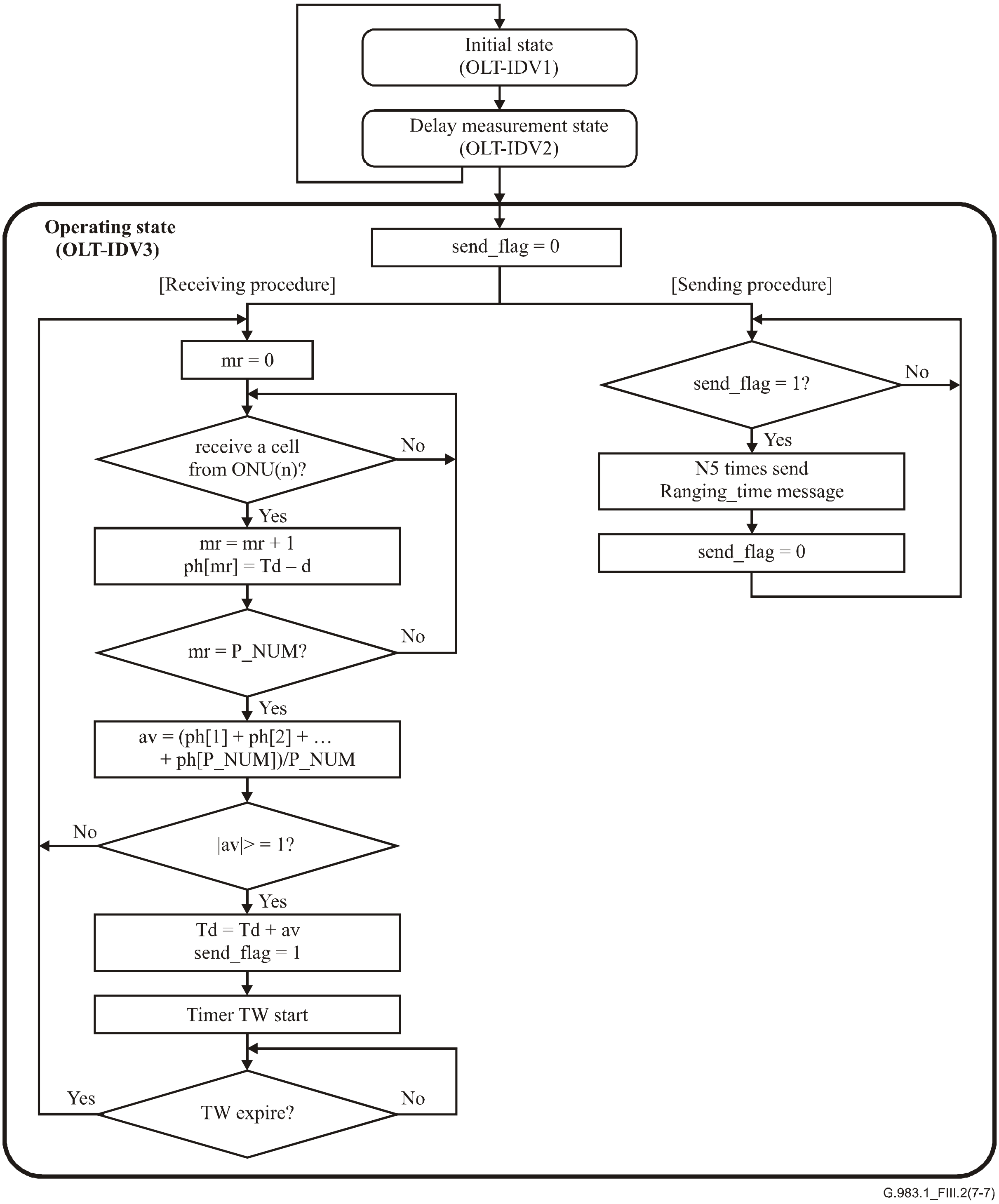


Figure III.2/G.983.1 – Ranging flow [OLT] (example) ***(sheet 6 of 7)***



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 III.2/G.983.1 – Ranging flow [OLT] (example) ***(sheet 7 of 7)***

Appendix IV

Access network survivability

IV.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, which is appropriate for this appendix. Its implementation depends on the realization of the economical system.

This appendix presents some possible duplex 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. For further information, please see ITU-T Rec. G.983.5.

IV.2 Possible switching types

There are two types of protection switching:

i) automatic switching; and

ii) forced switching,

which are in an analogy of SDH system. 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 the 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 IV.1 shows the duplex 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.

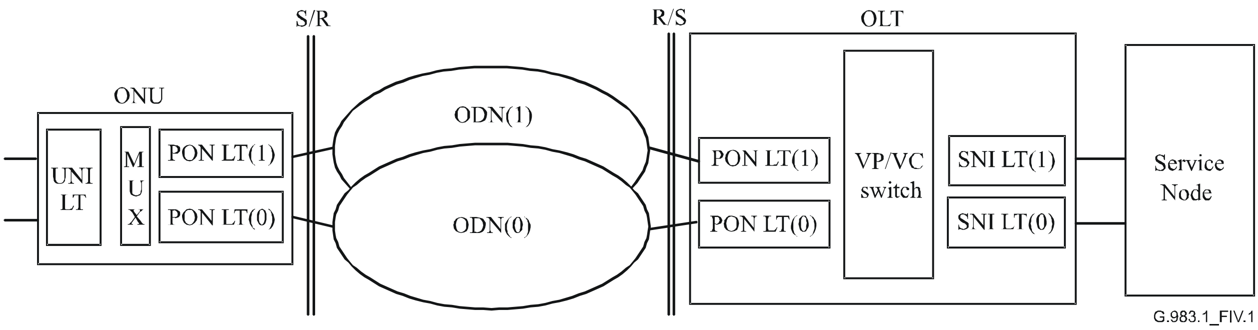


Figure IV.1/G.983.1 – Duplex system model

IV.3 Possible duplex ATM-PON configurations and characteristics

There can be several types of duplex ATM-PON system, as shown in Figure IV.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 IV.2 a), since the switching is only applied for the optical fibres. Also in Figure IV.2 b), any switching protocol is not required, since the switching is carried out only in the OLT.

IV.3.1 Configuration examples

Type A: The first configuration doubles only the optical fibres, as shown in Figure IV.2 a). In this case, the ONUs and OLTs are singular.

Type B: The second one [Figure IV.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 duplexing the ONUs, although only the SLT side can be recovered.

Type C: The third configuration [Figure IV.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 standby facilities. Therefore, the full duplex cost enables a high reliability.

Type D: If the ONUs are installed in the customer buildings, the in-house wiring may or may not be duplexed. 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 duplex configuration. Based on this consideration, the last one [Figure IV.2 d)] permits a partial duplexing on the ONU side. This Figure shows an example where there are duplex 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 standby 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.

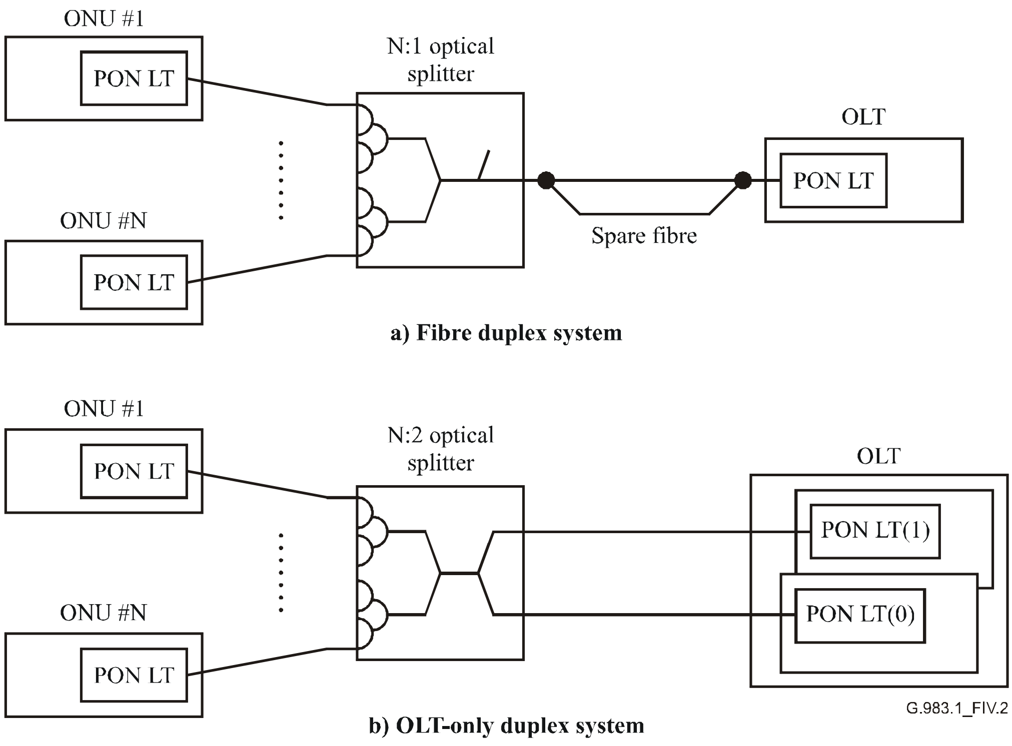
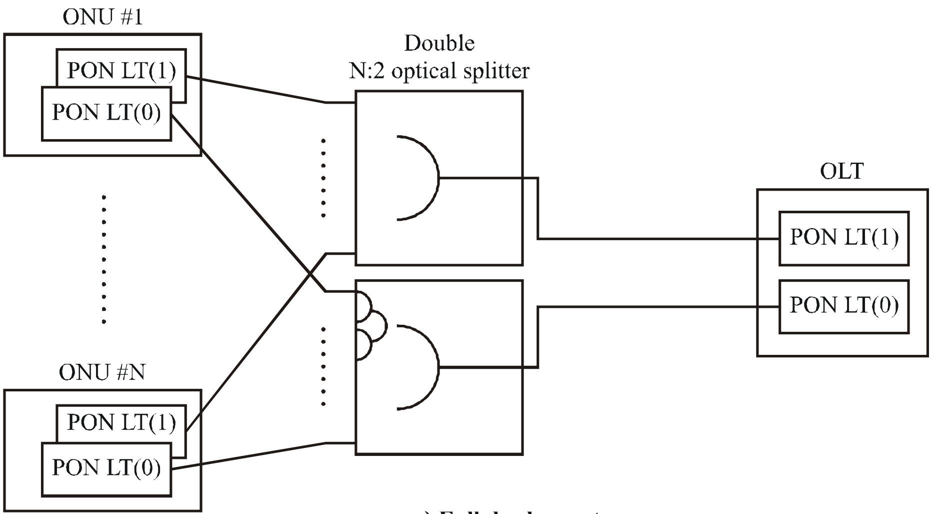
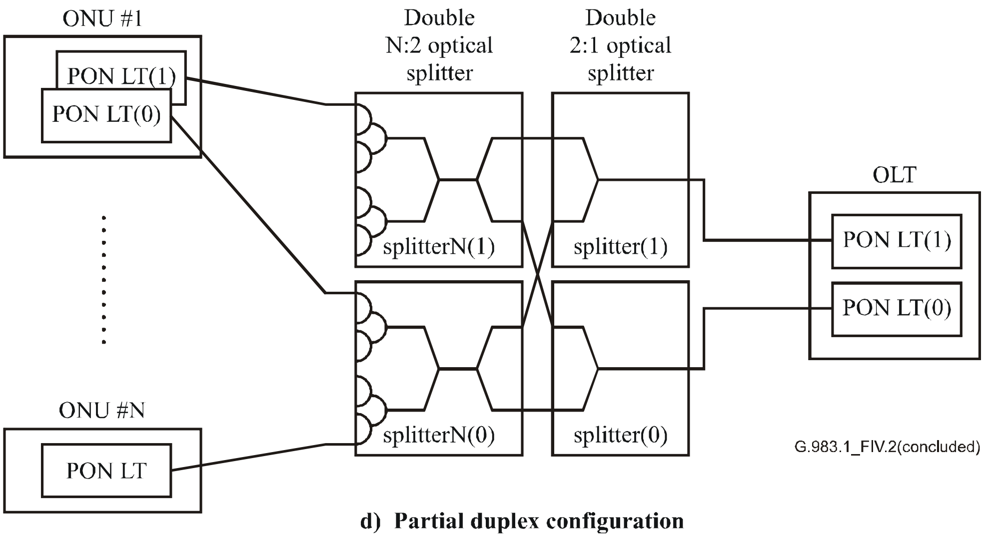


Figure IV.2/G.983.1 – Duplex ATM-PON system



c) Full duplex system



d) Partial duplex configuration

Figure IV.2/G.983.1 – Duplex ATM-PON system *(concluded)*

IV.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 standby 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 standby 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 are the same as Type B.

IV.4 Requirements

i) The protection switching function should be optional.

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

iii) All the configuration examples of IV.3 will be possible, even though they are optional functions.

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

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

Regarding the last requirement, one implementation of the POTS service node (exchange) requires the cell loss period to be less than 120 ms. 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.

IV.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.

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