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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

A broadband optical access system with enhanced survivability

ITU-T Recommendation G.983.5

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ITU-T Recommendation G.983.5

A broadband optical access system with enhanced survivability

Summary

This Recommendation describes flexible access networks using optical fibre technology based on ITU-T Rec. G.983.1. Specifically, it describes the functions that extend ITU-T Rec. G.983.1 to enable survivability-protection enhancements for the delivery of highly reliable services. It describes B-PON survivability architectures, protection performance criteria, and protection-switching criteria and protocols.

Source

ITU-T Recommendation G.983.5 was prepared by ITU-T Study Group 15 (2001-2004) and approved under the WTSA Resolution 1 procedure on 6 January 2002.

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.

NOTE

In this Recommendation, the expression "Administration" is used for conciseness to indicate both a telecommunication administration and a recognized operating agency.

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As of the date of approval of this Recommendation, ITU had received notice of intellectual property, protected by patents, which may be required to implement this Recommendation. However, implementors are cautioned that this may not represent the latest information and are therefore strongly urged to consult the TSB patent database.

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ITU-T Recommendation G.983.5

A broadband optical access system with enhanced survivability

1 Scope

This Recommendation describes the extended functions for B-PON systems defined in ITU-T Rec. G.983.1 to enable protection functions. It is based on Appendix IV/G.983.1. In particular, it focuses on the protection-configuration types B and C described in that appendix.

This Recommendation discusses a number of protection feature and function choices and provides the necessary specifications in the PON layer to implement these choices. These include guidelines on performance objectives (for example, switching and detection time), application functionality (for example, revertive mode, non-revertive mode, extra traffic support, automatic switching, and forced switching), switching criteria and switching protocols (1+1, 1:1, 1:N, bidirectional and unidirectional mechanisms).

This Recommendation considers protection enhancements for the delivery of highly reliable services for a variety of B-PON network scenarios, including Fibre to the Cabinet (FTTCab) and Fibre to the Office (FTTO).

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; 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.

[1] ITU-T Recommendation G.652 (2000), *Characteristics of a single-mode optical fibre cable*.

[2] ITU-T Recommendation G.671 (2001), *Transmission characteristics of optical components and subsystems*.

[3] ITU-T Recommendation G.783 (2000), *Characteristics of synchronous digital hierarchy (SDH) equipment functional blocks*.

[4] ITU-T Recommendation G.841 (1998), *Types and characteristics of SDH network protection architectures*.

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

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

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

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

[9] ITU-T G.983.1 (1998), *Broadband optical access systems based on Passive Optical Networks (PON)*.

[10] ITU-T G.983.2 (2000), *The ONT management and control interface specification for ATM PON*.

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

[12] ITU-T I.326 (1995), *Functional architecture of transport networks based on ATM*.

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

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

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

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

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

3 Abbreviations

This Recommendation uses the following abbreviations:

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
E/O	Electrical/Optical
FTTB/C	Fibre to the Building/Curb
FTTCab	Fibre to the Cabinet
FTTH	Fibre to the Home
FTTO	Fibre to the Office
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

MSB	Most Significant Bit
MSP	Multiplex Section Protection
NT	Network Termination
OAM	Operation, Administration and Maintenance
OAN	Optical Access Network
ODF	Optical Distribution Frame
ODN	Optical Distribution Network
OLT	Optical Line Termination
ONT	Optical Network Termination
ONU	Optical Network Unit
OpS	Operations System
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
SD	Signal Degrade
SDH	Synchronous Digital Hierarchy
SF	Signal Fail
SN	Serial Number
SNI	Service Node Interface
SPC	Service Port Function
TC	Transmission Convergence
TDMA	Time Division Multiple Access
UI	Unit Interval
UNI	User Network Interface
UPC	Usage Parameter Control
UPF	User Port Function
VC	Virtual Channel
VoD	Video on Demand
VP	Virtual Path
VPI	Virtual Path Identifier
WDM	Wavelength Division Multiplexing

4 Definitions

This Recommendation defines the following terms:

4.1 1:1 protection: A system of 1:1 protection configuration carries traffic in the working equipment while the protection equipment stands by without serving any traffic. The 1:1 protection configuration is a special case of the more general 1:N protection where the protection equipment is shared among N sets of working equipment.

4.2 1+1 protection: A system of 1+1 protection configuration carries identical traffic in both working and protection equipment.

4.3 X:N protection architecture: A system of X:N protection architecture offers X protection PONs for N working PONs, where some or all of the protected ONUs on the working PONs can be connected to any of the X protection PONs.

4.4 bidirectional protection: Upon detecting a failure of its working equipment, a system of bidirectional protection configuration requires acknowledgement from the far-end protection equipment before switching to the protection equipment.

4.5 unidirectional protection: A system of unidirectional protection configuration can switch to protection equipment once it detects failure in its working equipment.

4.6 churning: Churning is a function that 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 B-PON system and can be activated for point-to-point downstream connections.

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

4.8 extra traffic: Lower priority traffic with respect to that being carried by the working entity. It is carried over the protection entity while the working entity is active. The extra traffic is not protected, i.e. when the protection entity is required to protect the traffic that is being carried over the working entity (due to a failure or forced/manual switch operation), the extra traffic is pre-empted.

4.9 grant: A grant is a short downstream message giving permission to a specific ONU to transmit an upstream cell. The OLT controls the distribution of grants to the ONUs and ensures good use of the upstream channel without data collisions.

4.10 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.

4.11 non-revertive: A protection configuration is non-revertive if the system does not switch back.

4.12 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.

4.13 Optical Distribution Network (ODN): An ODN provides the optical transmission means from the OLT towards the users, and vice versa. It utilises passive optical components.

4.14 Optical Line Termination (OLT): An OLT provides the network-side interface of the OAN, and is connected to one or more ODNs.

4.15 Optical Network Termination (ONT): An ONU used for FTTH and includes the User Port function.

4.16 Optical Network Unit (ONU): An ONU provides (directly or remotely) the user-side interface of the OAN, and is connected to the ODN. As far as the protection functions are concerned, ONU and ONT share the same functionality. Thus, only ONU is referenced in this Recommendation for the sake of clarity.

4.17 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.

4.18 revertive: A protection configuration is revertive if the system automatically switches back to the working equipment after it is repaired or recovered from a failure condition. Therefore, in a revertive protection configuration, the system has fixed working equipment. The protection equipment is used only when the working equipment is out of service.

4.19 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.

4.20 Time Division Multiple Access (TDMA): Transmission technique involving the multiplexing of many time slots onto the same time payload.

4.21 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 access 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.

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

4.23 Wavelength Division Multiplexing (WDM): Bidirectional multiplexing using different optical wavelength for up and downstream signals.

5 Architecture and requirements for a protected optical access network

5.1 Architecture and requirements

5.1.1 Service categories

The following service categories have been considered:

- Asymmetric broadband services (e.g. digital broadcast services, VoD, Internet, distance 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 narrow-band telephone services.
- Reliable services. The access network must be able to provide protection for user traffic that demands high levels of reliability against equipment or facility failures in the network.

5.1.2 Background and requirements

Network configuration is basically satisfied with the type B and type C configurations described in ITU-T Rec. G.983.1. The following items are required for the B-PON survivability architecture:

– Type B protection configuration. In this configuration type (shown in Figure 1), no equipment redundancy is provided in the ONUs. The protection-capable OLT performs switching if its working PON interface fails or its directly connected fibre breaks. G.983.1 compliant ONUs satisfy type B protection configuration without modification.

– Type C protection configuration. In this configuration type (shown in Figures 2 and 3), equipment redundancy is provided in both the OLT and ONUs. The protection-capable OLT performs switching if any PON interface in the OLT or ONUs fails or if any fibre in the ODN breaks. This Recommendation addresses the modifications to ITU-T Rec. G.983.1 necessary to support the type C protection configuration.

– Mixture of protected and unprotected ONUs in type C configuration. The protection functions shall allow a mixture of protected and unprotected ONUs. In certain fault scenarios, the unprotected ONUs may suffer service disruption while the protected ONUs are recovered.

– X:N variant of type C protection configuration. In this variant of configuration type C (shown in Figure 3), equipment redundancy is provided in the OLT (some or all of the Line Terminals (LTs)) and some or all ONUs. This variant allows protected ONUs to be connected to any of the protection LTs, independent of which working LT they belong to. This variant is optional.

– Extra traffic for type C configuration. Extra traffic should be able to be carried over the protection entities while the working entity is active. The extra traffic will not be protected. This option provides effective usage of bandwidth in the protection entities. It must be possible for an operator not to activate this extra traffic option.

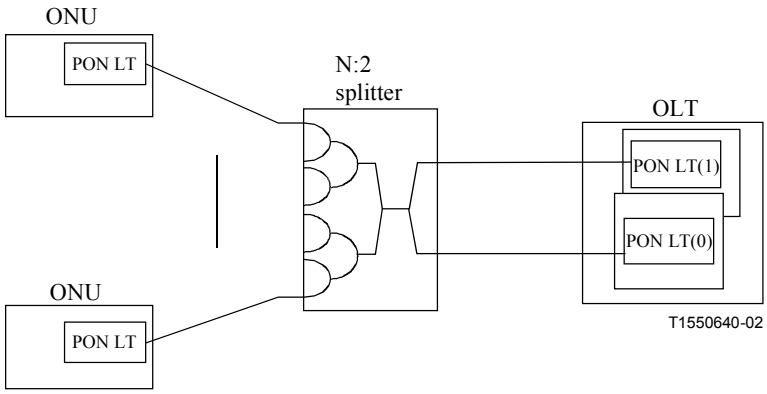


Figure 1/G.983.5 – Type B: OLT-only protected system

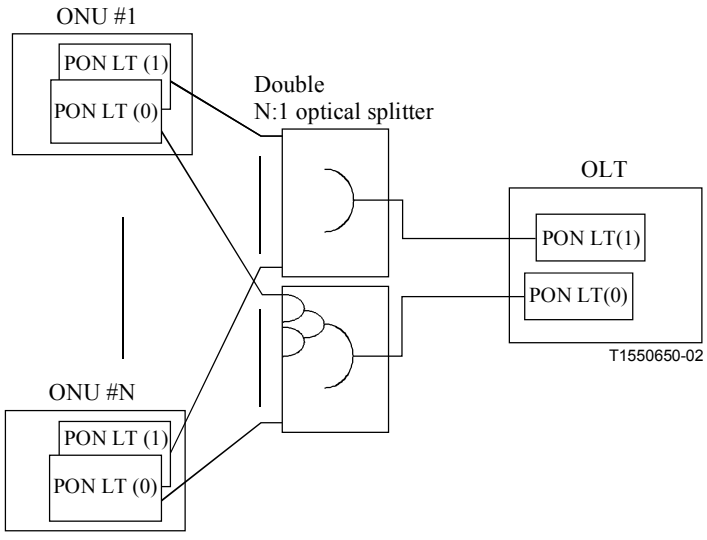


Figure 2/G.983.5 – Type C: Fully protected system, 1:1 and 1+1

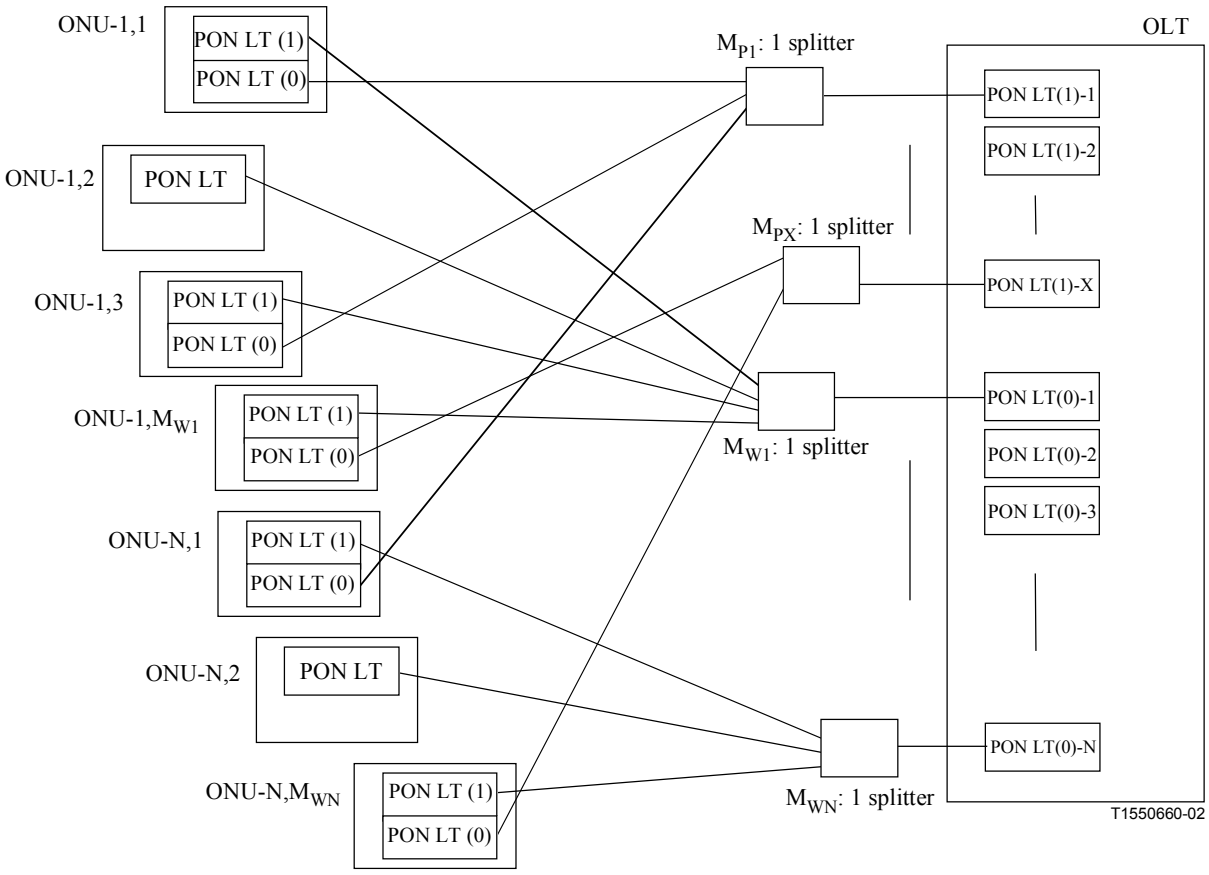


Figure 3/G.983.5 – Type C: X:N protection system

A redundant B-PON system shall satisfy the following requirements:

– It should be possible to have both the type B and type C protection configurations on the same OLT:
  - It should be possible to duplicate the OLT-PON-Interface and the fibres between the OLT and splitter and to duplicate the entire fibre path between the OLT and ONU for a set of ONUs.
  - The two configurations should be available on the same OLT, but not on the same ODN interface.

– It should be possible to have multi-vendor interoperability between OLT and ONU.

– In the type C configuration, it should be possible to have a mixture of protected and unprotected ONUs on one B-PON interface.

– The addition or removal of a protected ONU on a PON should not affect other ONUs on the same PON.

– It should be possible to have automatic switching, which would be triggered by a fault detection such as loss of signal, loss of cell delineation, signal degrade (e.g. BER becomes worse than the pre-determined threshold), etc.

– It should be possible to have forced switching, which would be activated by administrative events such as fiber rerouting, fiber replacement, etc.

– It is necessary to avoid unnecessary switching. Because unstable switching affects service quality, unnecessary protection switching and unnecessary revertive protection switching should not occur.

– It should be possible to realise switching without connection loss of the ATM connections.

– It should be possible for the operator to choose between a revertive and a non-revertive switching mode.

– The service halt time should be less than 50 ms if the extra traffic option is not used.

– The events or conditions that trigger automatic switching should be chosen among the G.983.1 OAM parameters.

– The chosen protocols and mechanisms must apply to the B-PON section layer.

– The type C configuration should be able to support extra traffic:

  • Extra traffic should be carried over the protection entities while the working entity is active and would not be protected. This capability will provide effective usage of bandwidth on the protection entities.

  • This requirement is applicable only for the type C configuration.

  • It must be possible for an operator not to activate the extra traffic option (e.g. to achieve a lower service interruption time).

5.2 Reference configuration

The reference configuration is the same as shown in Figure 2/G.983.1.

5.3 Functional blocks

Functional blocks are the same as described in 5.3/G.983.1.

5.4 ONU functional block

An example of a protected ONT (ONU with User Port Function) is shown in Figure 4. The ONT is active and decouples the access network delivery mechanism from the in-house distribution. The ONT core consists of redundant ODN interfaces, ODN interface switch, User Port, Transmission, Services and Customers Multiplexing (MUX)/demultiplexing functions and powering.

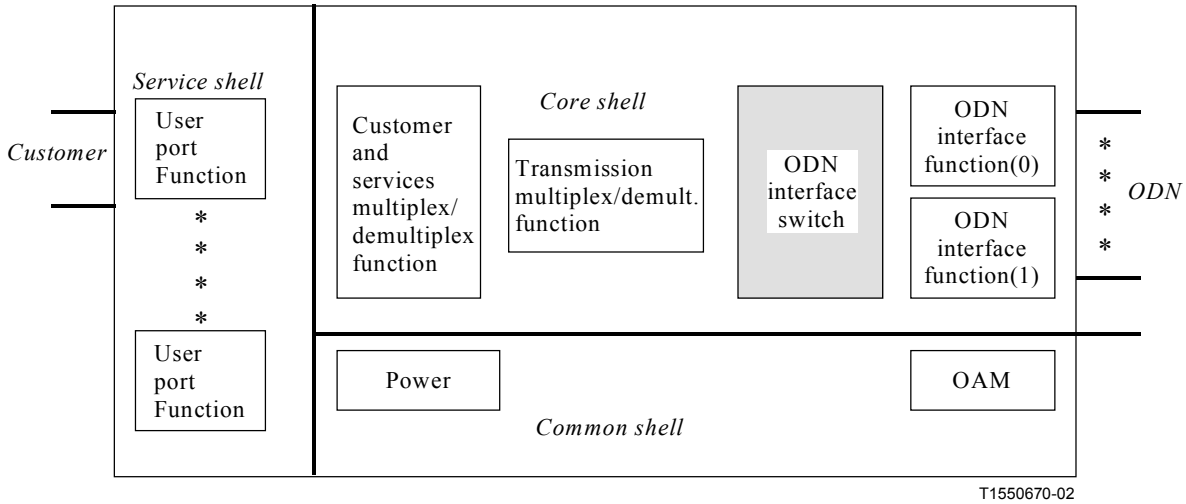


Figure 4/G.983.5 – ONU Functional Blocks

5.4.1 Optical Distribution Network (ODN) interface

The ODN interface handles the opto-electronic conversion process. The ODN interface extracts ATM cells from the downstream PON payload and inserts ATM cells into the upstream PON payload based on synchronisation acquired from the downstream frame timing. There are two ODN interfaces in a protected ONT/ONU.

5.4.2 Multiplexing

The Multiplexer (MUX) multiplexes service interfaces to the 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 the UNI to a user terminal. The User Port handles functions such as 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.

5.4.5 ODN interface switch

The ODN interface switch selects the 'in-service' ODN interface.

5.5 OLT functional block

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

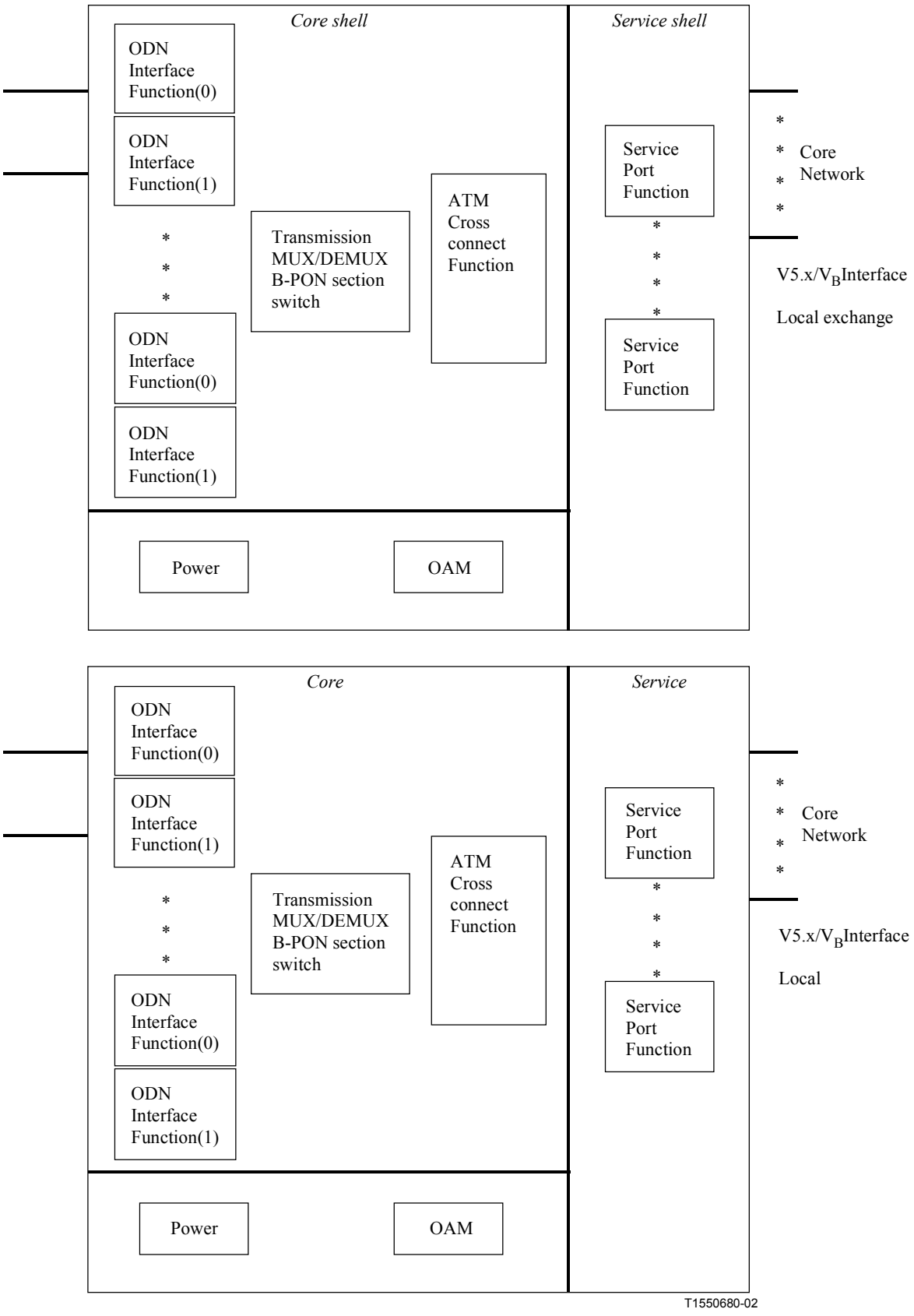


Figure 5/G.983.5 – OLT Functional Blocks

The OLT consists of three parts: the Service Port function, ODN interface and Transmission MUX/DEMUX/B-PON section switch for VP grooming (see Figure 5). (This combination is not intended to preclude the Virtual Channel (VC) layer function in the OLT. As discussed in ITU-T Rec. G.983.1, this function is for further study.)

1) *Service Port function*

   Same as in item 1) of 5.5/G.983.1.

2) *The Transmission MUX/DEMUX/B-PON section switch*

   This provides VP connections between the Service Port function and the ODN interface and different VPs are assigned to different services at the IF_{PON}. Various information flows such as the main data content, signalling, and OAM cells are exchanged by using VCs of the VP. The transmission MUX/DEMUX/B-PON section switch selects each B-PON section from the redundant ODN interfaces.

3) *ODN interface*

   The PON Line Terminal (LT) handles the opto-electronic conversion process. The ODN interface handles such functions as inserting ATM cells into the downstream PON payload and extracting ATM cells from the upstream PON payload. The ODN interface is redundant.

5.6 Optical Distribution Network (ODN) functional block

The ODN functional block is the same as in 5.6/G.983.1.

5.6.1 Passive optical elements

Passive optical elements are the same as in 5.6.1/G.983.1.

5.6.2 Optical interfaces

In the context of the reference configuration, Figure 6 shows the generic physical configuration of an ODN.

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.

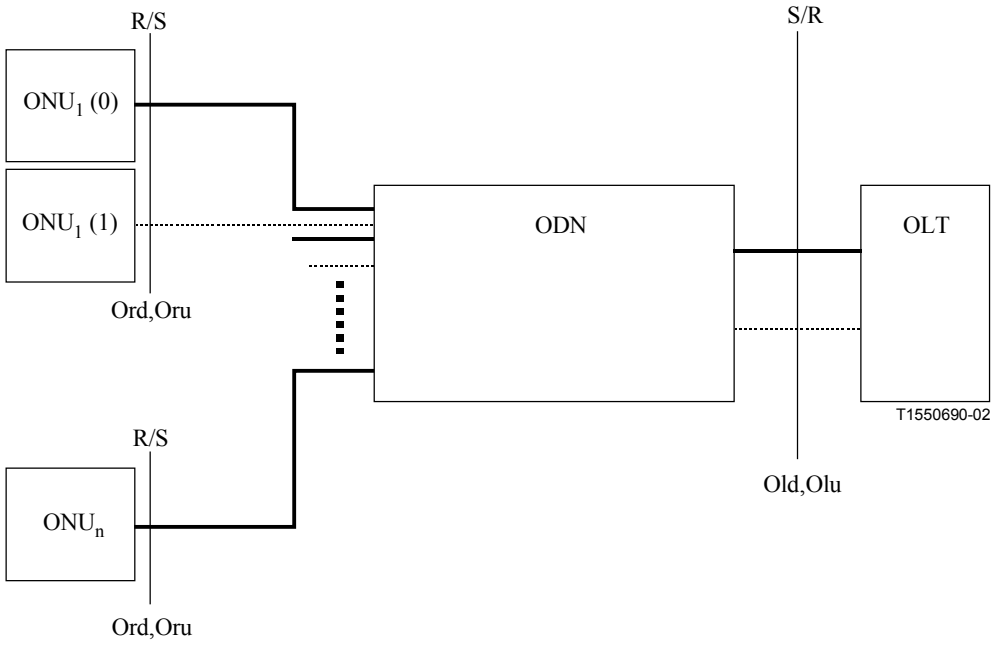
The following optical interfaces are defined in Figure 6:

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 will require at least two fibres for protected ONUs and OLTs, and may require more than two fibres, 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.



R and S: Reference points
Ord,Oru,Old,Olu : Optical interfaces
Bold solid lines represent one or more fibres
Dashed lines represent optional protection fibres

Figure 6/G.983.5 – Generic physical configuration of the Optical Distribution Network

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.

For the type B ODN configuration, the optical interface for the active/working OLT interface (O_{ld}) is the same as specified in ITU-T Rec. G.983.1. The O_{ld} interface for the inactive/stand-by OLT LT should not be "alight" (i.e. the laser diode should not be active) in order to prevent downstream interference.

For the type C ODN configuration, the optical interfaces at the OLT and ONU are the same as specified in ITU-T Rec. G.983.1.

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

Broadband access networks with protection functions can convey highly reliable services such as leased line or highly reliable VPN. These networks can also transmit the broadband services defined as G.983.1 and/or a mix of protected and unprotected services. In addition, these networks can transmit economical and lower reliability services as so called "extra traffic", which is pre-empted by highly reliable service when some failure occurs.

7 User Network Interface and Service Node Interface

The UNI and SNI are the same as in clause 7/G.983.1.

8 Optical network survivability requirements

8.1 Layer structure of the B-PON survivability optical network

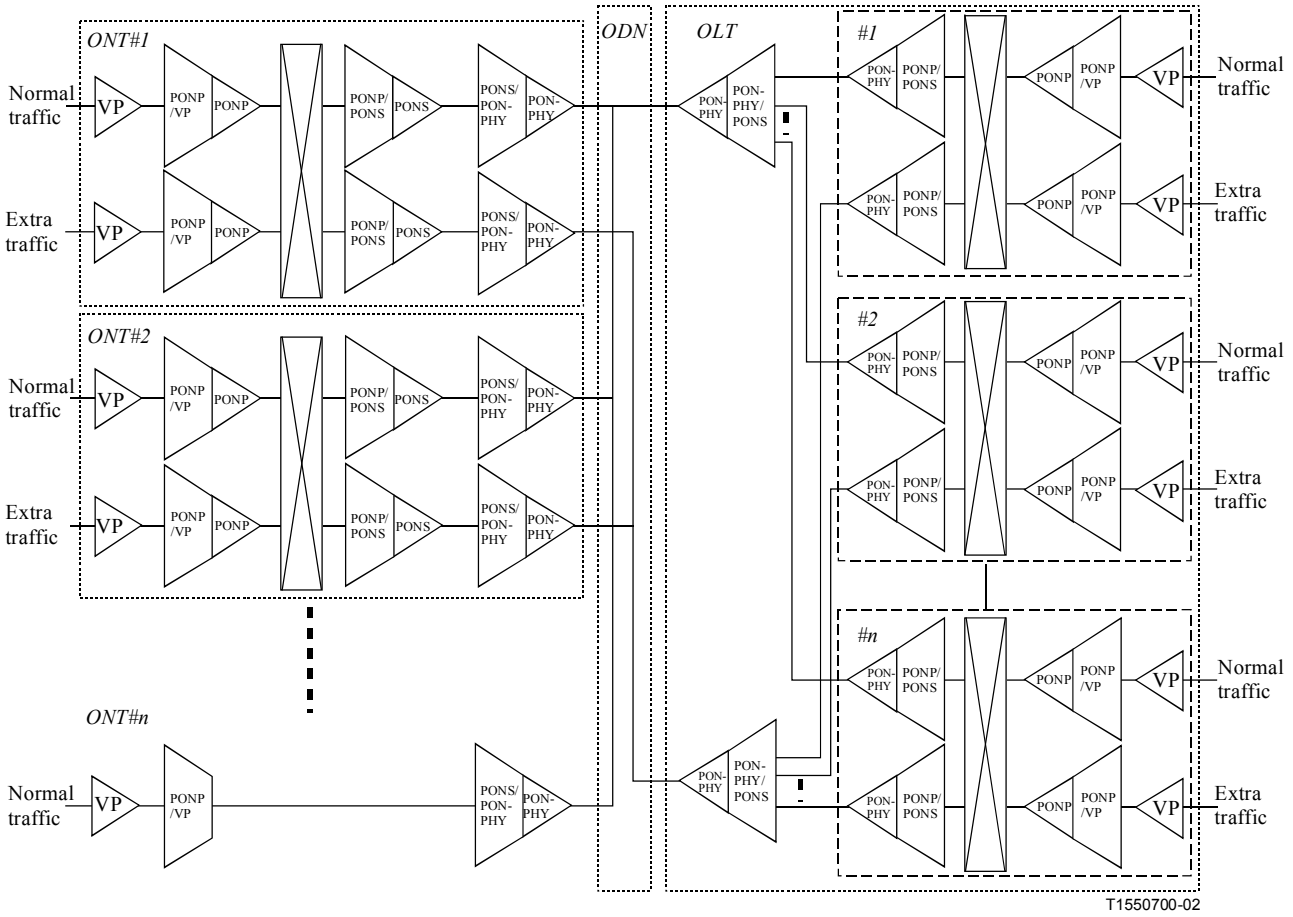
The layer structure of the optical network and the physical medium dependent layer requirements are the same as in 8.1 and 8.2/G.983.1.

Layer architecture of type C switching

In this clause, the layer architecture of B-PON protection is described. In order to protect each branch line and accommodate mixed protected and unprotected ONUs, survivability for the B-PON system is executed by switching each ONU's traffic. Figure 7 shows the layer architecture of B-PON protection, which is based on the ITU-T Rec. G.805 description. Figure 8 shows the multiplexing structure of the section/path layers between the OLT and ONU with the protection function.

A B-PON section is defined as the VP group between the OLT and an ONU. If "n" ONUs are connected to an OLT, then there are "n" B-PON sections. These sections are supervised using PLOAM cells as the TC layer function.

The B-PON section layer protection function is not on the ATM layer, but it is established in the TC layer between one ONU and OLT section including all VPI paths in the ONU, and is executed independently for each branch line failure. To do this, the B-PON section can be checked using the TC layer OAM function. This B-PON section-layer protection leads to higher reliability and flexibility in the ODN protection switching network.



PONS Passive Optical Network Section
PONP Passive Optical Network Protection
PON-PHY Passive Optical Network Physical
VP Virtual Path

Figure 7/G.983.5 – The layer architecture example in B-PON

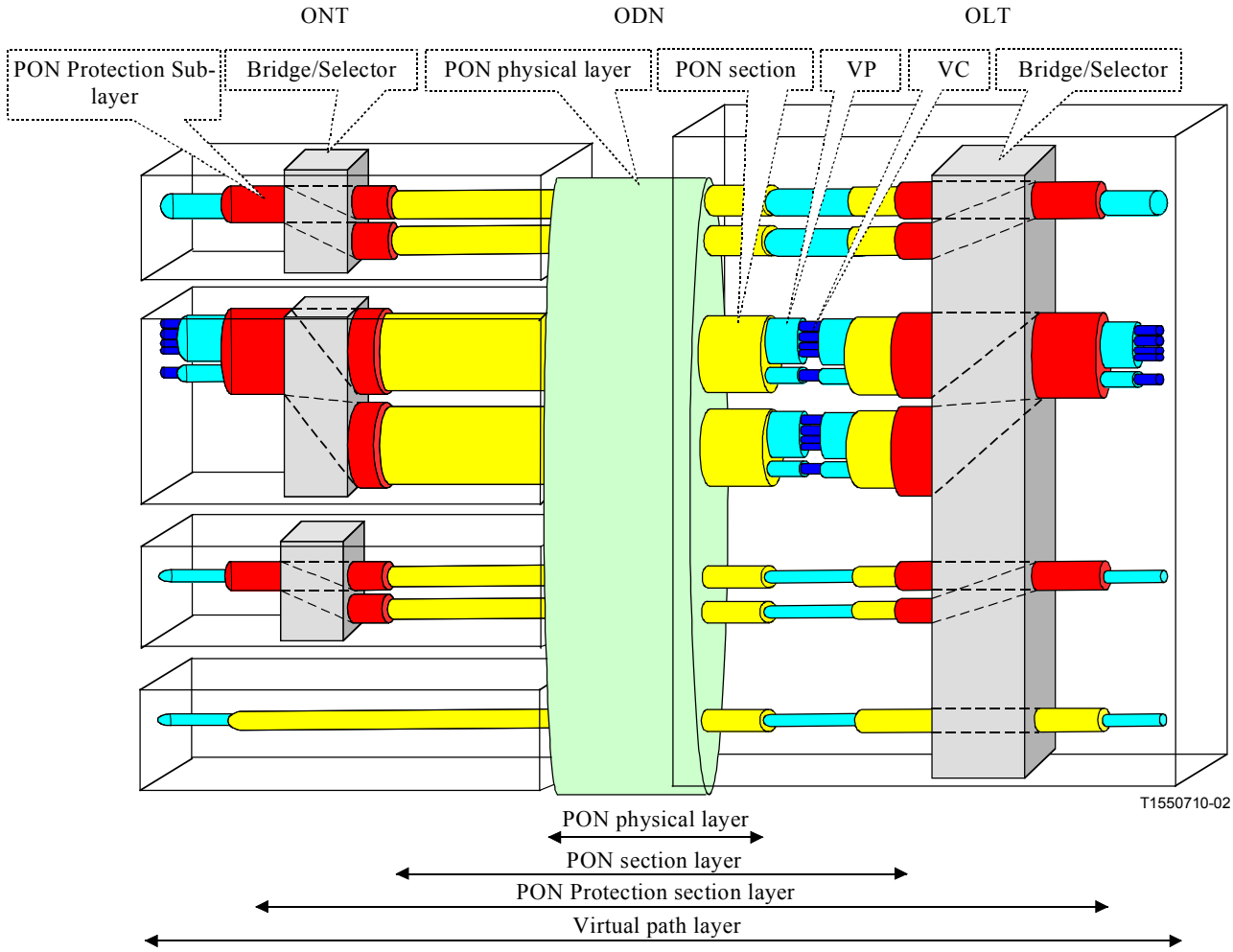


Figure 8/G.983.5 – The layer image in B-PON

8.2 Physical medium dependent layer requirements for B-PON

Same as ITU-T Rec. G.983.1.

8.3 Additional TC-layer requirements for B-PON survivability

For physical medium dependent layer requirements, reference is made to ITU-T Recs. G.983.1 and G.983.3. In addition to the TC layer functions already specified in ITU-T Rec. G.983.1, the following TC layer functions are added for the survivability application.

8.3.1 Duplex PON link identification

In the case of a protected system where a redundant PON protects the active PON, protection switching will be activated using specified messages in PLOAM cells or specific PON protocols. This sequence requires that the line numbers of the OLT must exactly match those of the ONU. The line identifier is assigned to a transmitter based on the interconnection scheme between the OLTs and ONUs. The line identifier is periodically sent to both the OLT and ONU to check whether the received line identifier is the same as the equipment's own identifier. This is defined in the PON Section Trace (PST) message. Each piece of equipment can then verify its continued connection to the intended transmitter. If the received line number differs from the equipment's line number, the equipment generates an alarm, MIS (Link Mismatching). In case of an unprotected system, link mismatching is optional.

8.3.2 Additional messages in the PLOAM channel for survivability

PLOAM messages are described in 8.3.8.1/G.983.1. For B-PON survivability, the PST message is redefined to include an additional PLOAM message for survivability. This PST message is shown in Table 1.

Table 1/G.983.5 – PST Message definition

	Message Name	Function	Direction	Trigger	Number of times sent	Effect of receipt
15	PST message (Broadcast Message) (If OLT needs to send the same message to all ONUs, it can send this message.)	To check the OLT-ONU connectivity in a redundant configuration and to perform APS. Priority level is 1.	OLT → ONU	Send it when common message for all ONUs should be sent simultaneously.	Same as the individual trigger condition.	Same as the individual message. (See Note)
	PST message (Individual Message)	To perform APS. Priority level is 1.		Send it at a certain rate or when OLT detects the APS trigger to change K1/K2 bytes.	1 time/sec or when K1/K2 bytes should be changed.	ONU checks K1/K2 bytes and performs APS. (See Note)
28	PST message	To check the OLT-ONU connectivity in a redundant configuration and to perform APS. Priority level is 1.	OLT ← ONU	Send it a certain rate or when ONU detects the APS trigger to change K1/K2 bytes.	1 time/sec or when K1/K2 bytes should be changed.	OLT checks link number with own link number and generates a Link Mismatch (MIS) if different or OLT checks K1/K2 bytes and performs APS.
NOTE – ONU checks link number with own link number and generates a Link Mismatch (MIS) if different. This is checked by sending either individual or broadcast messages**.**						

8.3.3 Message formats

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

8.3.3.1 Downstream message formats

Downstream message formats shall be referenced to ITU-T Rec. G.983.1. The PST message shown in Table 2 is added for the survivability application.

Table 2/G.983.5 – Downstream message formats

PST message		
Octet	**Content**	**Description**
35	01000000 or PON_ID	Broadcast message to all ONUs or individual message to one ONU
36	10000000	Message identification "PST"
37	Linenumber	Can be 0 or line identifier
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	

8.3.3.2 Upstream message formats

Upstream message formats shall be referenced to ITU-T Rec. G.983.1. The PST message shown in Table 3 is added for the survivability application.

Table 3/G.983.5 – Upstream message formats

PST message		
Octet	**Content**	**Description**
2	PON_ID	Indicates the ONU sourcing this message
3	10000010	Message identification "PST"
4	Linenumber	Can be 0 or line identifier
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	

8.4 Ranging Method

Same as ITU-T Rec. G.983.1.

8.5 Protection switching

8.5.1 PON Protection function

Type B switching architecture

No specific requirements for type B configuration ONUs are foreseen.

For the OLT, two new functions are required: a select function to choose the PON-IF and a shut-down function for the stand-by PON-IF.

Type C switching architecture

For type C configuration, the B-PON section protection is required. One B-PON section corresponds to one connection between an OLT and an ONU, and may contain several TCONTs and VPI paths. B-PON section protection is executed independently by each branch line failure. This permits mixed connection of protected and unprotected ONUs and leads to higher reliability and flexibility in the ODN switching network.

1:1 and 1+1 architecture

There are two types of protection architecture:

i) *1:1 architecture*

In the source direction, the working entity conveys the traffic in the normal case. If the working entity fails or a forced/manual switch is executed, the protection entity conveys the traffic.

ii) *1+1 architecture*

In the source direction, the signal is bridged to both the working and protection entities. In the sink direction, one source signal (which must have good transmission quality) is selected.

NOTE – Only the 1:1 architecture can support extra traffic.

Figures 9 and 10 show the 1:1 and 1+1 switching architecture, respectively.

X:N architecture

In this scheme, X protection PONs are provided for N working PONs (with X between 1 and N). The N working PONs can have a mixture of protected and unprotected ONUs. The protected ONUs can be connected to any of the X protection PONs, so that protected ONUs belonging to the same working PON can be connected to different protection PONs and protected ONUs belonging to different working PONs can be connected to the same protection PON.

This scheme is compatible with both the 1:1 and 1+1 switching implementations and is independent of protocol. It provides protection against multiple failures in different working PONs with less than N protection PONs.

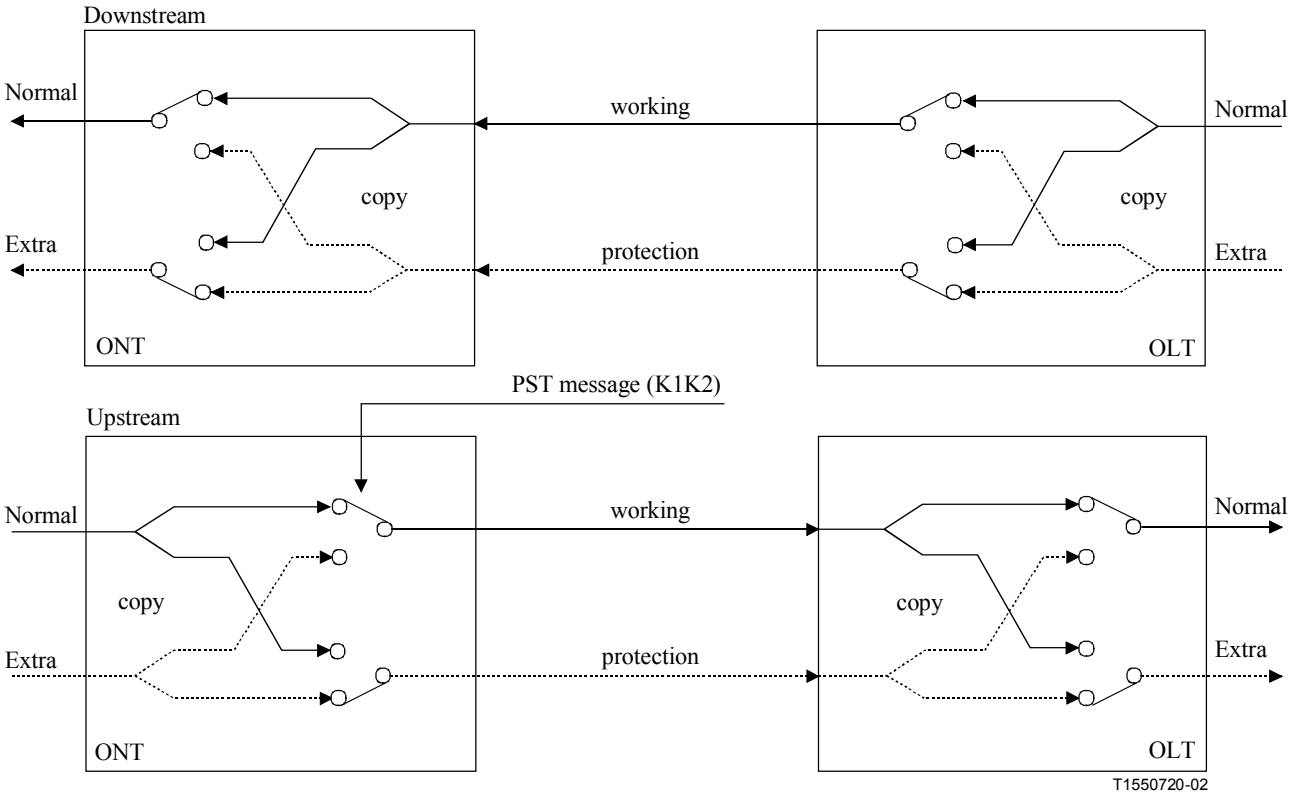


Figure 9/G.983.5 – 1:1 switching architecture

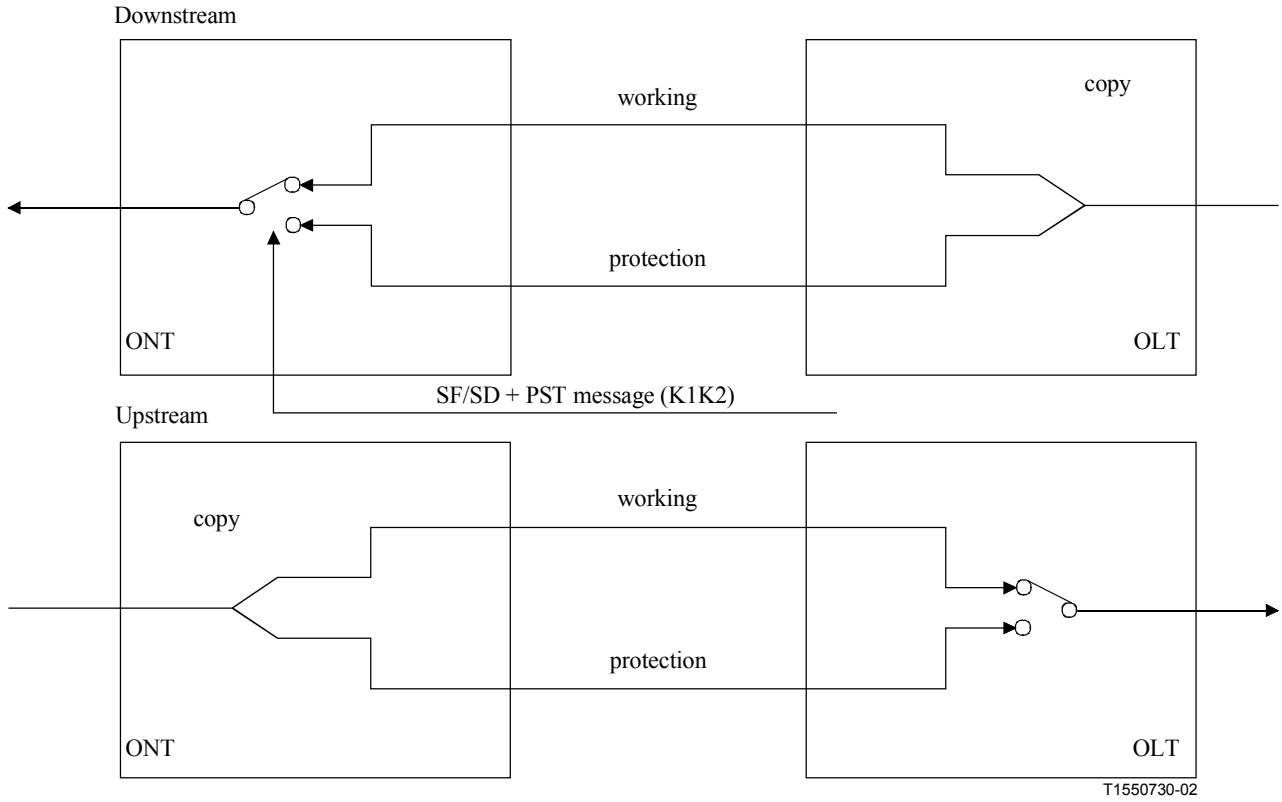


Figure 10/G.983.5 – 1+1 switching architecture

8.5.2 Protocols

To satisfy the requirements described in 5.1.2, the fast switching protocol described in Annex A is recommended.

8.5.3 Switching criteria

Basically, type B switching does not require any communication between the OLT and ONUs, and forced and automatic switching are executed only at the OLT side. The trigger for automatic switching should be the same as for type C.

Type C switching commands are described as follows.

1) *Externally initiated commands*

   Externally initiated commands (e.g. forced switch/manual switch operation) are always issued by the OLT side.

2) *Automatically initiated commands*

   Automatic protection switching is based on the failure conditions of the working and protection B-PON sections. Signal Fail (SF) and Signal Degrade (SD) commands are provided by the OLT and ONU.

The expected switching triggers (Signal Failure or Signal Degrade) are listed below.

a) *Trigger of SF on the OLT*

   The OLT recognizes an SF condition when it detects the following alarms:

   – LOSi, LCDi, CPEi, OAMLi, SUFi, LOAi, PEEi, DFi, TF, and
   – equipment failure or removal of PON LT (0/1).

b) *Trigger of SD on the OLT*

The OLT recognizes an SD condition when it detects the following alarm:

– SD.

c) *Trigger of SF on the ONU*

The ONU recognizes an SF condition when it detects the following alarms:

– OAML, FRML, LCD, LOS, PEE, DIS, TF, and

– equipment failure or removal of PON LT (0/1).

d) *Trigger of SD on the ONU*

The ONU recognizes an SD condition when it detects the following alarm:

– SD.

Switching triggers detected by the ONU are transferred by the K1 byte in the PST message to the OLT.

The TC layer alarms are detected on both the working and protection sides.

8.5.4 Performance

Detection time depends on the frequency at which data/PLOAM cells are transmitted. In particular, SD detection time may be long in lower-speed services. SF detection time should be under 10 ms for data transmission rates greater than 1.5 Mbit/s.

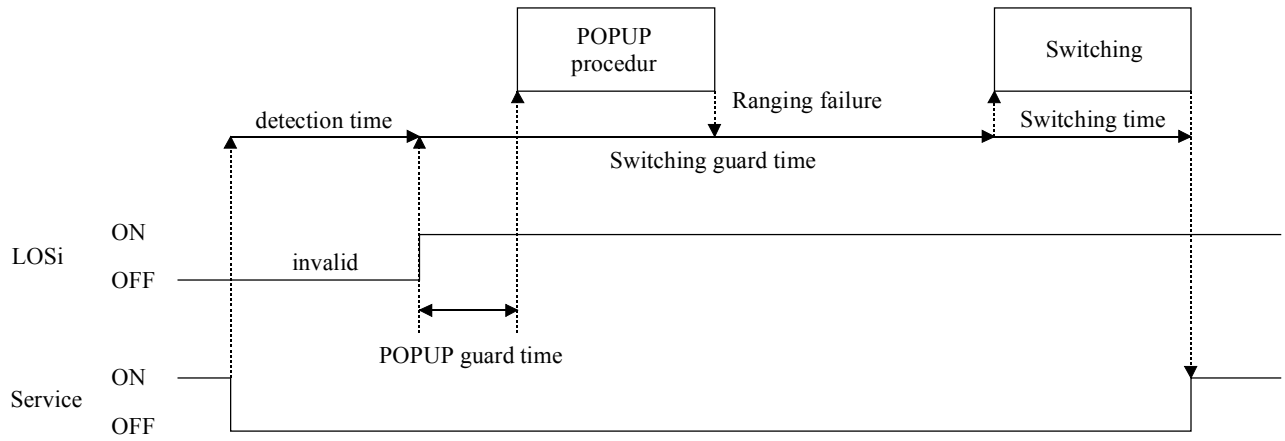
The definitions of detection time, switching guard time and switching time are shown in Figures 11 and 12. Figure 11 illustrates the relation between switching time and detection time when the optional POPUP procedure is used. (The POPUP procedure is the ranging protocol used when the ONT is in the POPUP state (O10) defined in ITU-T Rec. G.983.1.) These figures indicate that switching may be executed after the POPUP procedure fails to give the system a chance to recover working traffic via the POPUP procedure and, hence, to avoid unnecessary switching. When a system does not use the POPUP procedure, switching guard time may be very short. Figure 12 explains the relation between switching time and detection time when the POPUP procedure is not used.

When a PON is not carrying extra traffic, the service_halt_time should be under 50 ms for 32 ONUs, where the service_halt_time is defined as:

service_halt_time = detection_time + switching_guard_time + switching_time

Switching guard time and POPUP guard time are set in practical systems. The priority for reranging and switching is set according to these guard times.

i) Example of POPUP ranging failure (switching executes)



ii) Example of POPUP ranging success (switching does not execute)

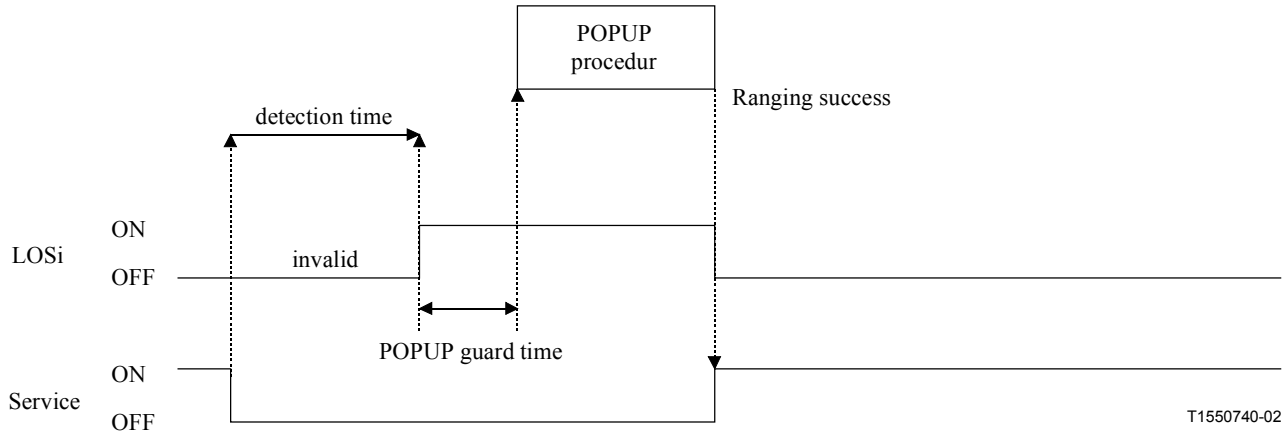


Figure 11/G.983.5 – Protection switching typical model (With POPUP procedure)

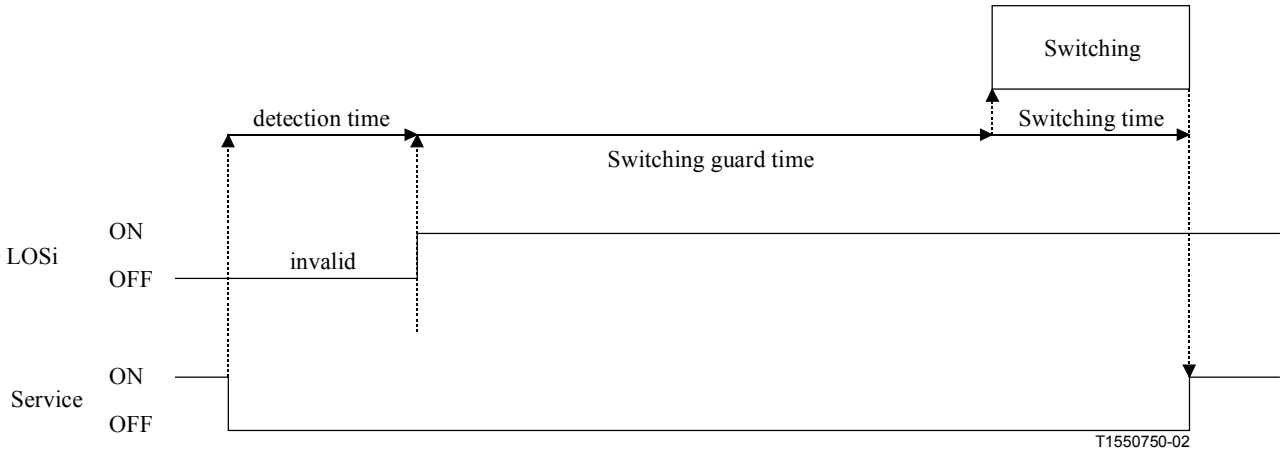


Figure 12/G.983.5 – Protection switching typical model (Without POPUP procedure)

9 Operations Administration and Maintenance (OAM) functionality

Same as ITU-T Rec. G.983.1.

10 Performance

Same as ITU-T Rec. G.983.1.

11 Environmental condition

Same as ITU-T Rec. G.983.1.

12 Safety

Same as ITU-T Rec. G.983.1.

Annex A

Fast switching protocol for the B-PON access network

This annex describes the survivability architecture for B-PON and the method of using MSP bytes and MSP commands.

A.1 Survivability Architecture

A.1.1 1:1 architecture (required)

The 1:1 architecture is shown in Figure A.1 and this architecture is required.

In the downstream direction, both normal and extra traffic are broadcast to selectors that choose the type of traffic (normal or extra) that is to be transmitted onto the ODN. In the ONU, there is a simple function that selects the correct traffic flow from the OLT.

In the upstream direction, the survivability mechanism is essentially the same (as the downstream). Both normal and extra traffic are sent to selectors in the ONU, which routes the appropriate traffic stream to the OLT. In the OLT, a simple selection function chooses the traffic stream.

For both upstream and downstream, if extra traffic is not supported, the selector at the receiver side may be replaced by a simple merger.

Each of the selectors must select the opposite signal to the one chosen by the other selector, e.g. if one selector in the OLT selects normal traffic, the other selector must select extra traffic. In the ONU, the same selector choices are required.

Switching is accomplished in the transmitting end via the selectors, which are set based on PST messages from the OLT. In the event of a failure that affects only downstream traffic, the ONU must notify the OLT of the failure in order to initiate switching. In this case, the ONU will cease to send any cells in response to grants on the working PON. This will cause a LOSi in the OLT and the switching will be initiated.

Switching between working and protection PONs is only possible if the standby TC layer alarms are not active and the PST message transmission is valid.

The VPI/VCI values of normal traffic and extra traffic shall be different to perform fast switching.

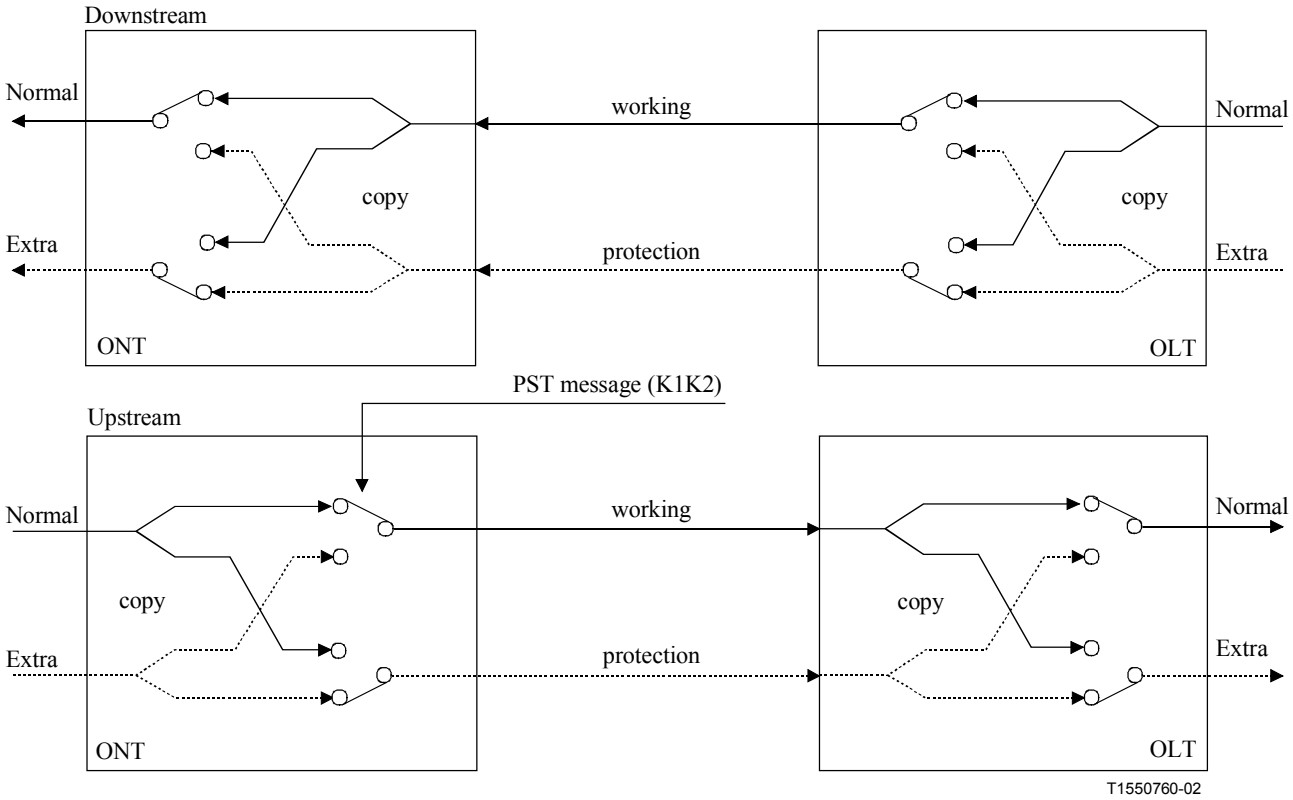


Figure A.1/G.983.5 – 1:1 Architecture

A.1.2 1+1 Architecture (optional)

The 1+1 Architecture is shown in Figure A.2. This architecture is optional.

In the downstream direction, the traffic is bridged to both the working and the protection PONs. In the ONU, the traffic is selected based on signal quality and/or PST messaging.

In the upstream direction the same functionality exists. Traffic is bridged to both working and protection PONs and on the receive side a selection mechanism selects traffic based on signal quality and provisioning.

Switching is initiated at the receiver that first detects a fault. In the event of a failure that effects only downstream traffic, the ONU must notify the OLT of the failure in order to complete the switching event. In this case, the ONU will cease to send any cells in response to grants on the working PON. This will cause a LOSi in the OLT and the switching action will be completed.

Extra traffic is not supported in this architecture.

Switching between working and protection PONs can be executed only if the destination traffic is valid.

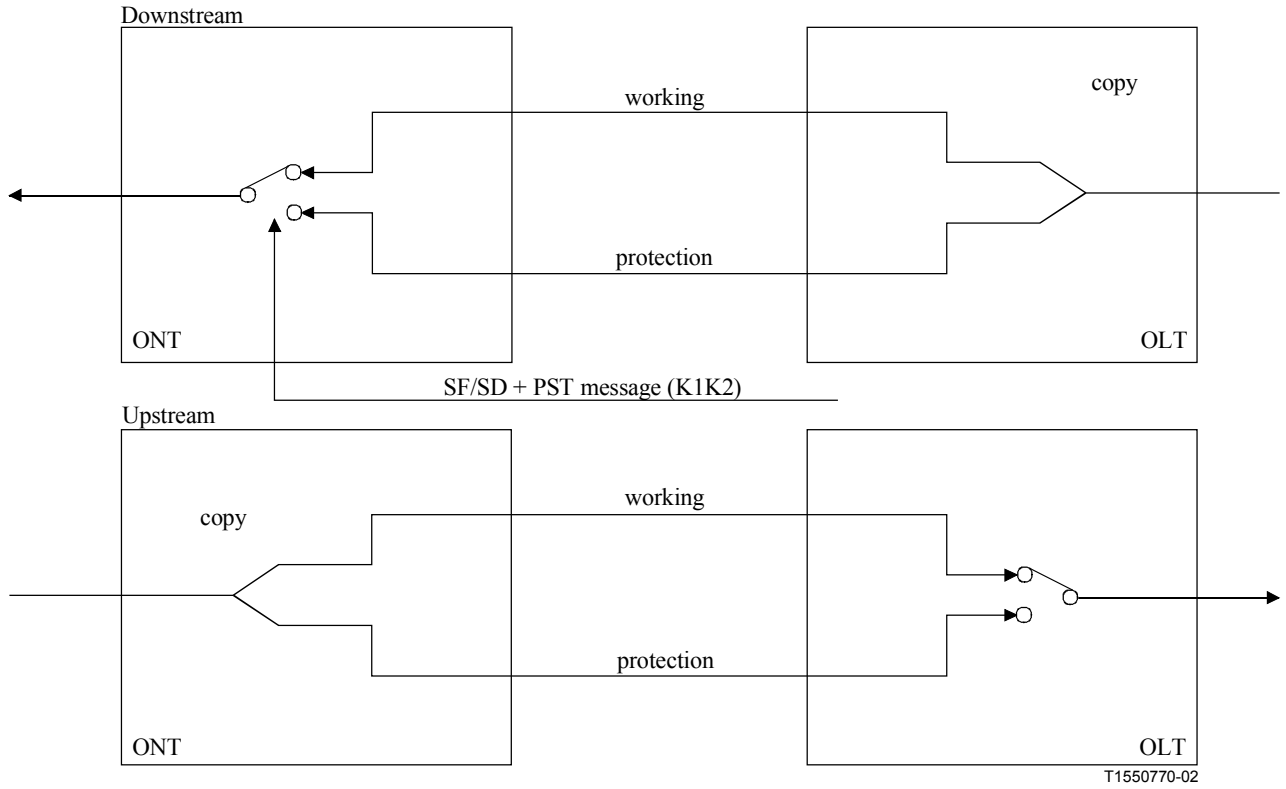


Figure A.2/G.983.5 – 1+1 Architecture

A.2 MSP bytes

This switching protocol uses a part of K1/K2 bytes defined in Annex A/G.783 to control the selector and bridge in the ONU. The bit assignments for these bytes and the bit-oriented protocol are defined in the following.

A.2.1 K1 byte

As the OLT is the master of the switching, the OLT uses the following requests in the sent K1:

Lockout of protection, Forced switching, Signal fail low priority, Signal degrade low priority, Manual switching, Wait to Restore, Do Not revert and No Request.

In response to requests from the OLT, the ONU uses following requests in the sent K1:

Reverse request and No request.

A.2.2 K1 byte generation rules

Refer to A.1.2/G.783.

A.2.2.1 In bidirectional operation

The B-PON system only supports bidirectional operation.

In the OLT, the local request is sent in the K1 byte.

In the ONU, two responses shall be sent in response to the OLT request.

The reverse request shall be sent when the ONU can perform the upstream switch.

The no request shall be sent when the ONU releases or does not perform the upstream switch.

A.2.3 Revertive/non-revertive modes

Refer to A.1.3/G.783.

Non-revertive operation is also applicable to the 1:1 architecture.

A.2.4 K2 byte

Refer to A.1.4/G.783.

As the ATM-PON system does not indicate MS-AIS and MS-RDI in bits 6 to 8, these bits can indicate the switching mode (i.e. bidirectional, using code 101).

A.2.5 Control of the upstream switch in the ONU and the downstream switch in the OLT

In the OLT, the local request is the switching trigger of the downstream switch.

In the ONU, the local request or the remote request is the switching trigger of the upstream switch.

If the protection section is in a SF condition, the switches in the OLT and ONU are released.

A.2.6 Transmission and acceptance of MSP Bytes

Refer to A.1.8/G.783.

As the MSP message is in the PLOAM cell, it is protected by the CRC-8 and hence can be accepted as valid when the CRC-8 detects no error.

A.3 MSP commands

There are five switching commands and two control commands in A.2/G.783.

As the lockout of working channel command cannot be transmitted to the ONU by the MSP bytes, the ONU does not stop switching the upstream switch if the downstream SF or SD is detected even if the lockout of working channel would like to be performed. Therefore the lockout of protection command can be used on behalf of the lockout of working channel command.

The exercise command is not allowed in order to avoid unnecessary switching.

As a result, the following commands are specified for B-PON survivability.

– Clear;

– Lockout of protection;

– Forced switch;

– Manual switch.

A.4 Switching Sequence

For PST message transmission, only the PST message from the protection side is used. If the PST message is received with an invalid CRC or both line failure, the OLT and ONU should select the working side.

A.4.1 1:1 bidirectional operation with non-revertive mode

When the protection section is not in use, null channel is indicated on both sent K1 and K2 bytes. The working channel should be bridged and switched to the working section at the head section. The null channel is bridged and switched to the protection section at the head end.

When a failure condition is detected at the ONU, the K1 byte in the protection section informs the OLT of the priority. The bridge and switch action is also performed at the ONU. The K2 byte shows the new bridge status.

The received K1 byte is compared with the local request at the OLT. The higher priority is chosen as the K1 byte order with the channel number. The bridge and switch action is also performed at the OLT. The K2 byte shows the new bridge status.

If single failure occurs in the ONU, the switching operation is completed.

When a failure condition is detected at the OLT, the K1 byte in protection section informs the ONU of the priority. The bridge and switch action is also performed at the OLT. The K2 byte shows the new switching status.

The received K1 byte is compared with the local request at the ONU. The switching order is performed as the result of the highest priority. The K1 byte from the ONU informs the OLT of the highest priority at the ONU. The K2 byte also shows the switching status at the ONU.

The OLT confirm the switching status in the ONU with the received K2 byte. If single failure occurs in the OLT, the switching operation is completed.

If the ONU detects the signal failure, it stops the upstream signal. This is a part of ranging state diagram. This also helps the fast failure notification to the OLT. When the failure is recovered, the OLT and ONU inform the opposite side of the Wait To Restore notification in the K1 byte. After WTR time is expired, the OLT sends the Do not Revert or No Request and the ONU sends Reverse Request or No request depending on the bridge status. If it is the case of non-revertive mode, WTR timer may not be used. In such case, DNR sends after the failure is recovered.

An example is given in Table A.1.

Table A.1/G.983.5 – 1:1 bidirectional operation with non-revertive mode example

Scenario	Failure Condition or state	K1/K2 Bytes		Action	
		ONU→OLT	OLT→ONU	ONU	OLT
No. 1 Upstream SF and recovery on working section	No failure traffic is on the working section.	00000000/00001101	00000000/00001101		
	SF is detected on the working section at OLT.		11000001/00011101		Bridge and switch the working channel to the protection section.
		00100001/00011101		Bridge and switch the working channel to the protection section.	
	SF is cleared at OLT . Non revertive mode		01100001/00011101		
			00010001/00011101		Wait to restore is expired.
		00100001/00011101		Wait to restore is expired.	
No. 2 Upstream SD and recovery on working section	No failure traffic is on working section	00000000/00001101	00000000/00001101		
	SD is detected on working section at OLT		10100001/00011101		Bridge and switch the working channel to the protection section.
		00100001/00011101		Bridge and switch the working channel to the protection section.	
	SD is cleared. Non revertive mode		01100001/00011101		
			00010001/00011101		Wait to restore is expired.

Table A.1/G.983.5 – 1:1 bidirectional operation with non-revertive mode example

Scenario	Failure Condition or state	K1/K2 Bytes		Action	
		ONU→OLT	OLT→ONU	ONU	OLT
No. 3 Upstream SF and recovery on protection section	No failure traffic is on protection section.	00100001/00011101	00010001/00011101		
	SF is detected on protection section at OLT		11000000/00001101		Bridge and switch the working channel to the working section.
		00100001/00001101		Bridge and switch the working channel to the working section.	
	SF is cleared. Non revertive mode		01100000/00001101		
			00000000/00001101		Wait to restore is expired.
		00000000/00001101		Wait to restore is expired.	

Table A.1/G.983.5 – 1:1 bidirectional operation with non-revertive mode example

Scenario	Failure Condition or state	K1/K2 Bytes		Action	
		ONU→OLT	OLT→ONU	ONU	OLT
No. 4 Upstream SD and recovery on protection section	No failure traffic is on protection section.	00100001/00011101	00010001/00011101		
	SD is detected on protection section at OLT.		10100000/00001101		Bridge and switch the working channel to the working section.
		00100000/00001101		Bridge and switch the working channel to the working section.	
	SD is cleared. Non revertive mode		01100000/00001101		
			00000000 00001101		Wait to restore is expired.
		00000000/00001101			

Table A.1/G.983.5 – 1:1 bidirectional operation with non-revertive mode example

Scenario	Failure Condition or state	K1/K2 Bytes		Action	
		ONU→OLT	OLT→ONU	ONU	OLT
No. 5 Downstream SF and recovery on working section	No failure traffic is on working section.	00000000 00001101	00000000/00001101		
	SF is detected on the working section at ONU.	11000001/00011101		Stop the upstream signal on working section at ONU. Bridge and switch the working channel to the protection section.	
	SF is detected on the working section at OLT.		11000001/00011101		Detect LOSi . Bridge and switch the working channel to the protection section.
	SF is cleared at OLT and ONU.	01100001/00011101	01100001/00011101	Recover the upstream signal after ranging.	
			00010001/00011101		Wait to restore is expired.
		00100001/00011101		Wait to restore is expired.	

Table A.1/G.983.5 – 1:1 bidirectional operation with non-revertive mode example

Scenario	Failure Condition or state	K1/K2 Bytes		Action	
		ONU→OLT	OLT→ONU	ONU	OLT
No. 6 Downstream SD and recovery on working section	No failure traffic is on working section.	00000000/00001101	00000000/00001101		
	SD is detected on the working section at an ONU.	10100001/00011101		Bridge and switch the working channel to the protection section.	
			00100001/00011101		Bridge and switch the working channel to the protection section.
	SD is cleared at ONU.	01100001/00011101			
			00010001/00011101		
		00100001/00011101		Wait to restore is expired.	

Table A.1/G.983.5 – 1:1 bidirectional operation with non-revertive mode example

Scenario	Failure Condition or state	K1/K2 Bytes		Action	
		ONU→OLT	OLT→ONU	ONU	OLT
No. 7 Downstream SF and recovery on protection section	No failure traffic is on protection section.	00100001 00011101	00010001/00011101		
	SF is detected on the protection section at an ONU.	11000000/00001101		Stop the upstream signal on the protection section. Bridge and switch the working channel to the working section.	
			11000000/00001101		Detect LOSi. Bridge and switch the working channel to the working section.
	SF is cleared.	01100000/00001101	01100000/00001101		
			00000000/00001101		Wait to restore is expired.
		00000000/00001101		Wait to restore is expired.	

Table A.1/G.983.5 – 1:1 bidirectional operation with non-revertive mode example

Scenario	Failure Condition or state	K1/K2 Bytes		Action	
		ONU→OLT	OLT→ONU	ONU	OLT
No. 8 Downstream SD and recovery on protection section	No failure traffic is on protection section.	00100001/00011101	00010001/00011101		
	SD is detected on the protection section at an ONU.	10100000/00001101		Bridge and switch the working channel to the working section.	
			00100000/00001101		Bridge and switch the working channel to the working section.
	SD is cleared at ONU.	01100000/00001101			
		00000000/00001101		Wait to restore is expired.	
			00000000/00001101		
No. 9 Upstream SF on both working and protection section	No failure traffic is on working section.	00000000/00001101	00000000/00001101		
	SF is detected on the protection section at the OLT. SF is detected on the working section at the OLT.		11000000/00001101		Bridge and switch the working channel to the working section.
		00100000/00001101		Bridge and switch the working channel to the working section.	

Table A.1/G.983.5 – 1:1 bidirectional operation with non-revertive mode example

Scenario	Failure Condition or state	K1/K2 Bytes		Action	
		ONU→OLT	OLT→ONU	ONU	OLT
No. 10 Upstream SD on both working and protection section	No failure traffic is on working section.	00000000/00001101	00000000/00001101		
	SDs are detected on both working and protection sections at OLT.		10100000/00001101		Bridge and switch the working channel to the working section.
		00100000/00001101		Bridge and switch the working channel to the working section.	
No. 11 Upstream SF on the working section and SD on protection section	No failure traffic is on working section.	00000000/00001101	00000000/00001101		
	SF is detected on the working channel at the OLT. SD is also detected on the protection channel at the OLT.		11000001/00011101		Bridge and switch the working channel to the protection section.
		00100001/00011101		Bridge and switch the working channel to the protection section.	

Table A.1/G.983.5 – 1:1 bidirectional operation with non-revertive mode example

Scenario	Failure Condition or state	K1/K2 Bytes		Action	
		ONU→OLT	OLT→ONU	ONU	OLT
No. 12 Downstream SF on both working section and protection section	No failure traffic is on working section.	00000000/00001101	00000000/00001101		
	SF is detected on the protection section at the ONU. SF is also detected on the working section at the ONU.	11000000/00001101		Stop the upstream signal on both the working and protection section. Bridge and switch the working channel to the working section.	
			11000000/00001101		Detect LOSi on both the working and protection sections. Bridge and switch the working channel to the working section.

Table A.1/G.983.5 – 1:1 bidirectional operation with non-revertive mode example

Scenario	Failure Condition or state	K1/K2 Bytes		Action	
		ONU→OLT	OLT→ONU	ONU	OLT
No. 13 Downstream SF on the working section and SD on protection section	No failure traffic is on working section.	00000000/00001101	00000000/00001101		
	SF is detected on the working section at the ONU. SD is also detected on the protection section at the ONU.	11000001/00011101		Stop the upstream signal on the working section. Bridge and switch the working channel to the protection section.	
			11000001/00011101		Detect LOSi . Bridge and switch the working channel to the protection section.
No. 14 Downstream SD on both working and protection section	No failure traffic is on working section.	00000000/00001101	00000000/00001101		
	SDs are detected on both working and protection sections.	10100000/00001101		Bridge and switch the working channel to the working section.	
			00100000/00001101		Bridge and switch the working channel to the working section.

Table A.1/G.983.5 – 1:1 bidirectional operation with non-revertive mode example

Scenario	Failure Condition or state	K1/K2 Bytes		Action	
		ONU→OLT	OLT→ONU	ONU	OLT
No. 15 Upstream SF on protection section and Downstream SF on working section	No failure traffic is on working section.	00000000/00001101	00000000/00001101		
	SF is detected on the working section at the ONU. SF is detected on the protection section at the OLT.	11000001/00011101	11000000/00001101	Stop the upstream signal on the working section. Bridge and switch the working channel to the protection section.	Bridge and switch the working channel to the working section.
		11000001/00001101		Bridge and switch the working channel to the working section.	

Table A.1/G.983.5 – 1:1 bidirectional operation with non-revertive mode example

Scenario	Failure Condition or state	K1/K2 Bytes		Action	
		ONU→OLT	OLT→ONU	ONU	OLT
No. 16 Upstream SF on protection section and Downstream SD on working section	No failure traffic is on working section.	00000000/00001101	00000000/00001101		
	SF is detected on the protection section at the OLT. SD is detected on the working section at the ONU.	10100001/00011101	11000000/00001101	Bridge and switch the working channel to the protection section.	Bridge and switch the working channel to the working section.
		11010001/00001101		Bridge and switch the working channel to the working section.	
No. 17 Upstream SD on protection section and Downstream SF on the working section	No failure traffic is on working section.	00000000/00001101	00000000/00001101		
	SD is detected on the protection section at the OLT. SF is detected on the working section at the ONU.	11000001/00011101	10100000/00001101	Stop the upstream signal on the working section. Bridge and switch the working channel to the protection section.	Bridge and switch the working channel to the working section.
			11000001/00011101		Detect LOSi on the working section. Bridge and switch the working channel to the protection section.

Table A.1/G.983.5 – 1:1 bidirectional operation with non-revertive mode example

Scenario	Failure Condition or state	K1/K2 Bytes		Action	
		ONU→OLT	OLT→ONU	ONU	OLT
No. 18 Upstream SD on protection section and Downstream SD on the working section	No failure traffic is on working section.	00000000/00001101	00000000/00001101		
	SD is detected on the protection section at the OLT. SD is detected on the working section at the ONU.	10100001/00011101	10100000/00001101	Bridge and switch the working channel to the protection section.	Bridge and switch the working channel to the working section.
		10100001/00001101		Bridge and switch the working channel to the working section.	
No. 19 Upstream SF on working section and Downstream SF on protection section	No failure traffic is on working section.	00000000/00001101	00000000/00001101		
	SF is detected on the working section at the OLT. SF is detected on the protection section at the ONU.	11000000/00001101	11000001/00011101	Stop the upstream signal on the protection section. Bridge and switch the working channel to the working section.	Bridge and switch the working channel to the protection section.
	SF is detected on the working section at the ONU.		11000000/00001101		LOSi is detected on the protection section. Bridge and switch the working channel to the working section.

Table A.1/G.983.5 – 1:1 bidirectional operation with non-revertive mode example

Scenario	Failure Condition or state	K1/K2 Bytes		Action	
		ONU→OLT	OLT→ONU	ONU	OLT
No. 20 Upstream SD on working section and Downstream SF on the protection section	No failure traffic is on working section.	00000000/00001101	00000000/00001101		
	SD is detected on the working section at the OLT. SF is detected on the protection section at the ONU.	11000000/00001101	10100001/00011101	Stop the upstream signal on the protection section. Bridge and switch the working channel to the working section.	Bridge and switch the working channel to the protection section.
	SF is also detected on the protection section at the OLT.		11000000/00001101		Detect LOSi on the protection section. Bridge and switch the working channel to the working section
No. 21 Upstream SF on working section and Downstream SD on protection section	No failure traffic is on working section.	00000000/00001101	00000000/00001101		
	SF is detected on the working section at the OLT. SD is detected on the protection section at the ONU.	10100000/00001101	11000001/00011101	Bridge and switch the working channel to the working section.	Bridge and switch the working channel to the protection section.
		10100000/00011101		Bridge and switch the working channel to the protection section.	

Table A.1/G.983.5 – 1:1 bidirectional operation with non-revertive mode example

Scenario	Failure Condition or state	K1/K2 Bytes		Action	
		ONU→OLT	OLT→ONU	ONU	OLT
No. 22 Upstream SD on working section and Downstream SD on the protection section	No failure traffic is on working section.	00000000/00001101	00000000/00001101		
	SD is detected on the working section at the OLT. SD is detected on the protection section at the ONU.	10100000/00001101	10100001/00011101	Bridge and switch the working channel to the working section.	Bridge and switch the working channel to the protection section.
			10100001/00001101		Bridge and switch the working channel to the working section.
No. 23 Forced switch to protection section	No failure traffic is on working section.	00000000/00001101	00000000/00001101		
	Forced switch order		11100001/00011101		Bridge and switch the working channel to the protection section.
		00100001/00011101		Bridge and switch the working channel to the protection section.	

Table A.1/G.983.5 – 1:1 bidirectional operation with non-revertive mode example

Scenario	Failure Condition or state	K1/K2 Bytes		Action	
		ONU→OLT	OLT→ONU	ONU	OLT
No. 24 Forced switch to working section	No failure traffic is on protection section.	00100001/00011101	00010001/00011101		
	Forced switch order		11100000/00001101		Bridge and switch the working channel to the working section.
		00100000/00001101		Bridge and switch the working channel to the working section.	
			00000000/00001101		
		00000000/00001101			
No. 25 Manual switch and Downstream SD on working section	No failure traffic is on protection section.	00100001/00011101	00010001/00011101		
	SD is detected on the working section at the ONU. Manual Switch order	10100001/00011101	10000000/00001101	Bridge and switch the working channel to the protection section.	
	SD is higher priority than the manual switch.	10100001/00011101	10000000/00011101		Bridge and switch the working channel to the protection section after receiving the response from ONU.
	The manual switch results in failure.	10100001/00011101	00010001/00011101		

A.4.2 1:1 bidirectional operation with revertive mode

The difference between revertive mode and non-revertive mode is the behavior when the SF or SD condition in the working section is recovered.

An example is given in Table A.2.

Table A.2/G.983.5 – 1:1 bidirectional operation with revertive mode example

Scenario	Failure Condition or state	K1/K2 Bytes		Action	
		ONU→OLT	OLT→ONU	ONU	OLT
No. 1 recovery of the upstream SF on working section	No failure traffic is on the working section.	00000000/00001101	00000000/00001101		
	SF is detected on the working section at OLT.		11000001/00011101		Bridge and switch the working channel to the protection section.
		00100001/00011101		Bridge and switch the working channel to the protection section.	
	SF is cleared at OLT. Revertive mode.		01100001/00011101		
			00000000/00001101		Wait to restore is expired. Bridge and switch the working channel to the working section.
		00000000/00001101		Bridge and switch the working channel to the working.	

Table A.2/G.983.5 – 1:1 bidirectional operation with revertive mode example

Scenario	Failure Condition or state	K1/K2 Bytes		Action	
		ONU→OLT	OLT→ONU	ONU	OLT
No. 2 Downstream SD and recovery on working section	No failure traffic is on working section.	00000000/00001101	00000000/00001101		
	SD is detected on the working section at an ONU.	10100001/00011101		Bridge and switch the working channel to the protection section.	
			00100001/00011101		Bridge and switch the working channel to the protection section.
	SD is cleared at ONU.	01100001/00011101			
		00000000/00001101		Wait to restore is expired. Bridge and switch the working channel to the working section.	
			00000000/00001101		Bridge and switch the working channel to the working section.

A.4.3 1+1 bidirectional operation with non-revertive mode

The difference between 1+1 bidirectional operation with non-revertive mode and 1:1 bidirectional operation with non-revertive mode is the code of K2 byte. The behavior of 1+1 bidirectional operation with non-revertive mode is the same as that of 1:1 bidirectional operation with non-revertive mode.

An example is given in Table A.3.

Table A.3/G.983.5 – 1+1 bidirectional operation with non-revertive mode example

Scenario	Failure Condition or state	K1/K2 Bytes		Action	
		ONU→OLT	OLT→ONU	ONU	OLT
No. 1 Upstream SF and recovery on working section	No failure traffic is on the working section.	00000000/00000101	00000000/00000101		
	SF is detected on the working section at OLT.		11000001/00010101		Bridge and switch the working channel to the protection section.
		00100001/00010101		Bridge and switch the working channel to the protection section.	
	SF is cleared at OLT. Non revertive mode		01100001/00010101		
			00010001/00010101		Wait to restore is expired.
		00100001/00010101		Wait to restore is expired.	

Table A.3/G.983.5 – 1+1 bidirectional operation with non-revertive mode example

Scenario	Failure Condition or state	K1/K2 Bytes		Action	
		ONU→OLT	OLT→ONU	ONU	OLT
No. 2 Downstream SF and recovery on working section	No failure traffic is on working section.	00000000/00000101	00000000/00000101		
	SF is detected on the working section at ONU.	11000001/00010101		Stop the upstream signal on working section at ONU. Bridge and switch the working channel to the protection section.	
	SF is detected on the working section at OLT.		11000001/00010101		Detect LOSi . Bridge and switch the working channel to the protection section.
			01100001/00010101		
	SF is cleared at OLT and ONU.	01100001/00010101	01100001/00010101	Recover the upstream signal after ranging.	

A.4.4 1+1 bidirectional operation with revertive mode

The difference between 1+1 bidirectional operation with revertive and 1:1 bidirectional operation with revertive is the code of K2 byte. The behavior of 1+1 bidirectional operation with revertive mode is the same as that of 1:1 bidirectional operation with revertive mode.

An example is given in Table A.4.

Table A.4/G.983.5 – 1+1 bidirectional operation with revertive mode example

Scenario	Failure Condition or state	K1/K2 Bytes		Action	
		ONU→OLT	OLT→ONU	ONU	OLT
No. 1 recovery of the upstream SF on working section	No failure traffic is on the working section.	00000000/00000101	00000000/00000101		
	SF is detected on the working section at OLT.		11000001/00010101		Bridge and switch the working channel to the protection section.
		00100001/00010101		Bridge and switch the working channel to the protection section.	
	SF is cleared at OLT. Revertive mode.		01100001/00010101		
			00000000/00000101		Wait to restore is expired. Bridge and switch the working channel to the working section.
		00000000/00000101		Bridge and switch the working channel to the working.	

Table A.4/G.983.5 – 1+1 bidirectional operation with revertive mode example

Scenario	Failure Condition or state	K1/K2 Bytes		Action	
		ONU→OLT	OLT→ONU	ONU	OLT
No. 2 Downstream SD and recovery on working section	No failure traffic is on working section.	00000000/00000101	00000000/00000101		
	SD is detected on the working section at an ONU.	10100001/00010101		Bridge and switch the working channel to the protection section.	
			00100001/00010101		Bridge and switch the working channel to the protection section.
	SD is cleared at ONU.	01100001/00010101			
		00000000/00000101		Wait to restore is expired. Bridge and switch the working channel to the working section.	
			00000000/00000101		Bridge and switch the working channel to the working section.

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