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Amendment 1
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SERIES G: TRANSMISSION SYSTEMS AND MEDIA, DIGITAL SYSTEMS AND NETWORKS

Digital networks – Optical transport networks

Optical transport network: Linear protection

Amendment 1

Recommendation ITU-T G.873.1 (2017) – Amendment 1

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For further details, please refer to the list of ITU-T Recommendations.

Recommendation ITU-T G.873.1

Optical transport network: Linear protection

Amendment 1

Summary

Recommendation ITU-T G.873.1 defines the automatic protection switching (APS) protocol and protection switching operation for linear protection schemes of the optical transport network at the optical data unit k (ODUk) level. The protection schemes considered in this Recommendation are:

– ODUk subnetwork connection protection with inherent monitoring (1+1, 1:n);
– ODUk subnetwork connection protection with non-intrusive monitoring (1+1);
– ODUk subnetwork connection protection with sublayer monitoring (1+1, 1:n).
– ODUk compound link subnetwork connection group protection with inherent monitoring (1+1, 1:1).

In addition, client-related protection architectures are described.

Corrigendum 1 provides an editorial correction to the text in clause 7.1.

Amendment 1 adds ODUCn as a server layer of protected entities in Table 8-1 and provides minor editorial changes.

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FOREWORD

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Recommendation ITU-T G.873.1

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Editorial note: This is a complete-text publication. Modifications introduced by this amendment are shown in revision marks relative to Recommendation ITU-T G.873.1 (2017) plus its Corrigendum 1.

1 Scope

This Recommendation defines the automatic protection switching (APS) protocol and protection switching operation for ~~the ~~linear protection schemes ~~for ~~of the optical transport network (OTN) at the optical data unit k (ODUk) level. These schemes are based on the generic linear protection specifications in [ITU-T G.808.1]. The l~~L~~inear protection schemes considered in this Recommendation are:

– ODUk subnetwork connection protection with inherent monitoring (1+1, 1:n);

– ODUk subnetwork connection protection with non-intrusive monitoring (1+1);

– ODUk subnetwork connection protection with sublayer monitoring (1+1, 1:n);

– ODUk compound link subnetwork connection group protection with inherent monitoring (1+1, 1:1).

In addition, client-related protection architectures are described.

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. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

[ITU-T G.709] Recommendation ITU-T G.709/Y.1331 (~~2016~~2020), *Interfaces for the optical transport network*.

[ITU-T G.798] Recommendation ITU-T G.798 (2017), *Characteristics of optical transport network hierarchy equipment functional blocks*.

[ITU-T G.798.1] Recommendation ITU-T G.798.1 (2013), *Types and characteristics of optical transport network equipment*.

[ITU-T G.806] Recommendation ITU-T G.806 (2012), *Characteristics of transport equipment – Description methodology and generic functionality*.

[ITU-T G.808] Recommendation ITU-T G.808 (2016), *Terms and definitions for network protection and restoration*.

[ITU-T G.808.1] Recommendation ITU-T G.808.1 (2014), *Generic protection switching – Linear trail and subnetwork protection*.

3 Definitions

3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

Terms defined in [ITU-T G.808]:

– APS channel;
– extra traffic signal;
– head-end;
– normal traffic signal;
– null signal;
– protection communication channel;
– protection transport entity;
– protection group;
– signal;
– tail-end;
– working transport entity.

3.2 Terms defined in this Recommendation

None.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

AIS Alarm Indication Signal

APS Automatic Protection Switching

CBR Constant Bit Rate signal

CL_SNCG/I Compound Link Subnetwork Connection Group protection with Inherent monitoring

CSF Client Signal Fail

DNR Do Not Revert

ETC3 Ethernet Coding 1000BASE-X

EXER Exercise

FDI Forward Defect Indication

FS Forced Switch

HO Higher Order

LCK Locked ~~defect~~

LO Lower Order

LoP Lockout for Protection

MFAS Multiframe Alignment Signal

MS Manual Switch

NIM Non-Intrusive Monitor

NR No Request

OCI	Open Connection Indication
ODU[i]j	Optical Data Unit of level j and i (i is optional; i < j)
ODU[i]j_A	ODUkP to ODU[i]j Adaptation function
ODU[i]j_A_SK	ODUkP to ODU[i]j Adaptation Sink function
ODUj-21_A	ODUj payload type 21 Adaptation function
ODUk	Optical Data Unit of level k
ODUk_A	Optical Data Unit Adaptation of rate K
ODUk_A_Sk	ODUk Adaptation Sink function
ODUk[i]j	ODUj[/i] Optical Data Unit of level j or i (i is optional; i < j)
ODUkP	Optical Data Unit of level k, Path
ODUkT	Optical Data Unit of level k, Tandem connection sub-layer
OPU	Optical Payload Unit
OTN	Optical Transport Network
OTUk	Optical Transport Unit of level k
OTUkV	Functionally standardized Optical Transport Unit of level k
OTUk[V]	OTUk or OTUkV
PCC	Protection Communication Channel
PMOH	Path Monitoring Overhead
RR	Reverse Request
SD	Signal Degrade
SDH	Synchronous Digital Hierarchy
SF	Signal Fail
SMOH	Section Monitoring Overhead
SNC	Subnetwork Connection
SNC/I	Subnetwork Connection with Inherent monitoring
SNC/Nc	Subnetwork Connection with Non-intrusive monitoring of Client signal fail
SNC/Ne	Subnetwork Connection with Non-intrusive end-to-end monitoring
SNC/Ns	Subnetwork Connection with Non-intrusive Sublayer monitoring
SNC/S	Subnetwork Connection with Sub-layer monitoring
SSD	Server Signal Degraded
SSF	Server Signal Fail
TCM	Tandem Connection Monitoring
TCMOH	Tandem Connection Monitoring Overhead
TSD	Trail Signal Degraded
TSF	Trail Signal Fail
TTI	Trail Trace Identifier
WTR	Wait-to-Restore

5 Conventions

None.

6 Protection characteristics

6.1 Monitoring methods and conditions

Protection switching will occur based on the detection of certain defects on the transport entities (working and protection) within the protected domain. How these defects are detected is the subject of the equipment Recommendations (e.g., [ITU-T G.806] and [ITU-T G.798]). For the purpose of the protection switching controller, an entity within the protected domain has a condition of no defect (= OK), degraded (= S~~s~~ignal D~~d~~egrade ~~=~~(SD)), or failed (= S~~s~~ignal F~~f~~ail ~~=~~(SF)).

The customary monitoring methods are specified in clauses 11.2 and 11.3 of [ITU-T G.808.1] and in clause 14.1 of [ITU-T G.798] and are supported in the OTN as follows:

Inherent – Protection switching is triggered by defects detected at the ODUk link connection (e.g., server layer trail and server/ODUk adaptation function). The trail termination sink of an (OTUk[V] or ODUkP) server layer provides the ~~test~~ Trail S~~s~~ignal F~~f~~ail (TSF)- and ~~test~~ Trail S~~s~~ignal D~~d~~egraded (TSD)-based SF and SD protection switching criteria via the OTUk[V]/ODUk_A, ODUkP/ODU[i]j_A, or ODUkP/ODUj-21_A functions (as SSF and SSD). No defect detection is performed on the ODUk or ODU[i]j or ODUj signals themselves. It can be used for individual and for compound link group protection (CL_SNCG/I).

NOTE 1 – In contrast to SDH SNC/I, ODUk SNC/I can stretch only a single link connection, as the FDI/AIS defect resulting from further upstream server layer defects is not detected in the server/ODUk adaptation function. The limitation to a single server layer trail for SNC/I protection is given by the use of signal degrade (SD) as protection switching criteria. SD is only available from the OTUk[V] or HO ODUk trail that is locally terminated and not from further upstream OTUk[V] or HO ODUk trails. Furthermore, FDI/AIS, which provides information about defects in upstream OTUk[V] or HO ODUk trails, is not detected in the OTUk[V]/ODUk_A_Sk or ODUkP/ODU[i]j_A_Sk. For details of the atomic functions for TSF and TSD forwarding for the subnetwork connection (SNC) protection on LO ODU refer to [ITU-T G.798].

Figure 6-1 shows an OTUk or OTUkV monitored ODUk SNC/I protection configuration.

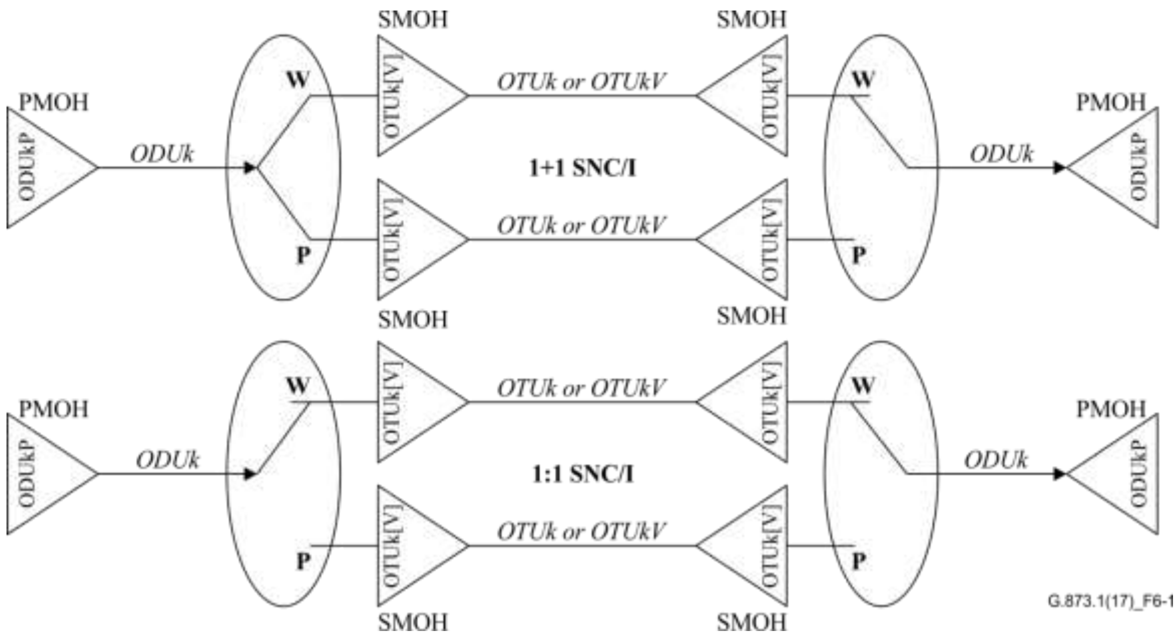


Figure 6-1 – OTUk or OTUkV monitored ODUk SNC/I protection configuration

Figure 6-2 shows a server ODUk monitored ODU[i]j/ODUj SNC/I protection configuration.

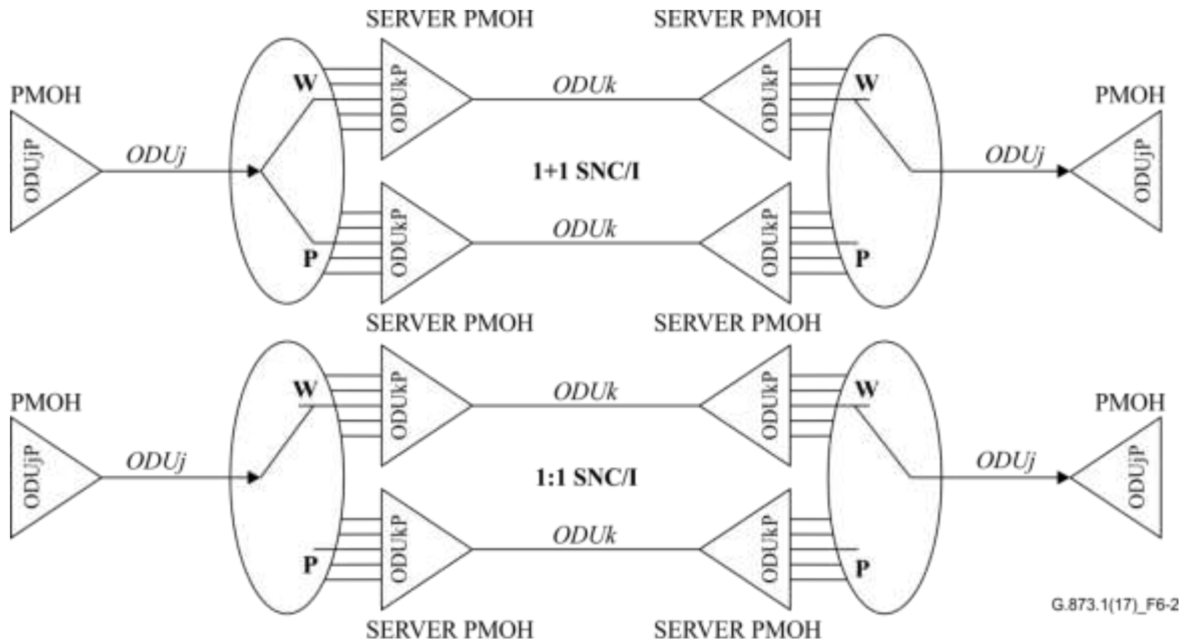


Figure 6-2 – Server ODUk monitored ODU[i]j/ODUj SNC/I protection configuration

Non-intrusive – Protection switching is triggered by a non-intrusive monitor of the ODUkP trail or ODUkT sub-layer trail at the tail-end of the protection group.

NOTE 2 – For a SNC/N protection the criteria according to [ITU-T G.798] are taken. This ensures that ODU~~k~~-AIS, ~~as well a~~ Locked (LCK), and~~or~~ O~~o~~pen C~~c~~onnection I~~i~~ndication (OCI) conditions are~~is~~ contributing to switch criteria of an ODU SNC/N protection. For details refer to clause 14.2 of [ITU-T G.798].

Figure 6-3 shows an ODUkP non-intrusively monitored ODUk SNC/Ne configuration and an ODUkT monitored ODUk SNC/Ns protection configuration.

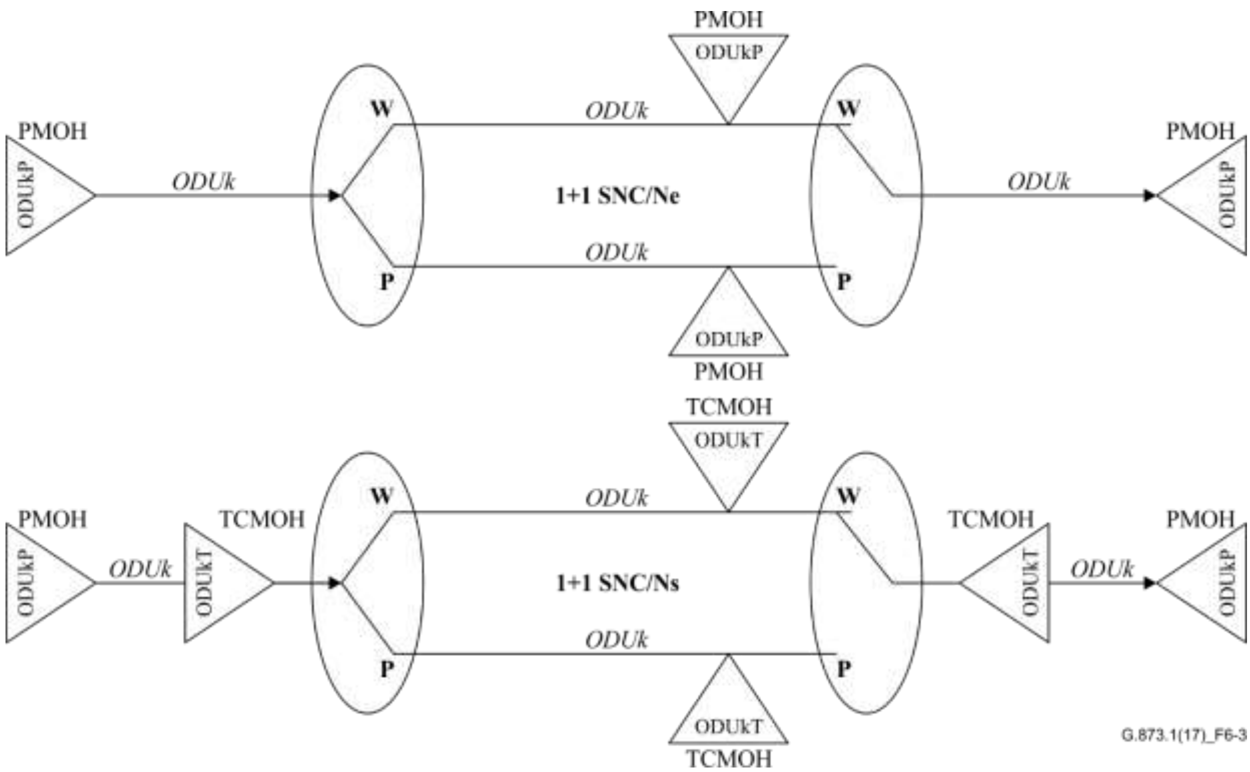


Figure 6-3 – ODUkP non-intrusively monitored ODUk SNC/Ne and ODUkT monitored ODUk SNC/Ns protection configurations

Sublayer – Protection switching is triggered by defects detected at the ODUkT sublayer trail (TCM). An ODUkT sublayer trail is established for each working and protection transport entity. Protection switching is therefore triggered only on defects of the protected domain. Figure 6-4 shows an ODUkT monitored SNC/S protection configuration.

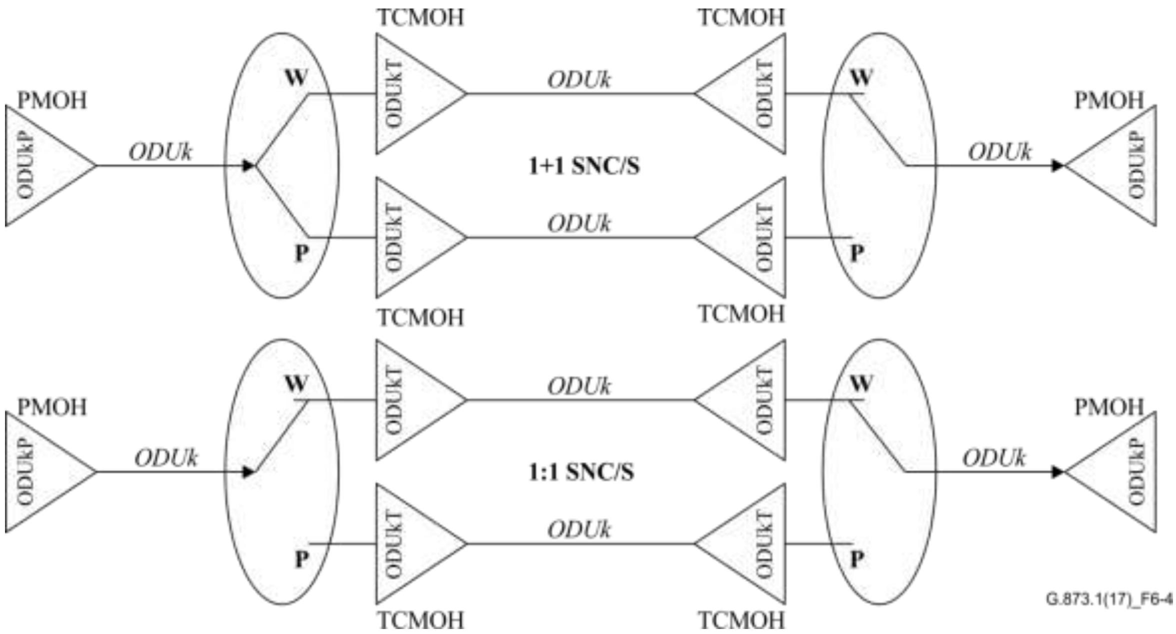


Figure 6-4 – ODUkT monitored SNC/S protection configuration

The protection switching controller does not care which monitoring method is used, as long as it can be given (OK, SD, SF) information for the transport entities within the protected domain. Some monitors or network layers may not have an SD detection method. Where this is the case, there is no need to use a different APS protocol – it would simply happen that an SD would not be issued from equipment that cannot detect it. Where an APS protocol is used, the implementation should not preclude that the far end declares an SD over the APS channel, even if the monitor at the near-end cannot detect SD.

NOTE 3 – In accordance with [ITU-T G.709], for sublayer monitoring, nesting and cascading are the default operational configurations. Overlapping is an additional configuration for testing purposes only. Overlapped monitored connections must be operated in a non-intrusive mode and not used for protection. Maintenance signals ODUk-AIS and ODUk-LCK must not be generated for overlapped monitored connections. For the case where one of the endpoints in an overlapping monitored connection is located inside a SNC protected domain while the other endpoint is located outside the protected domain, the SNC protection should be forced to working when the endpoint of the overlapping monitored connection is located on the working connection and forced to protection when the endpoint is located on the protection connection.

6.2 Protection switching performance

The transfer time T_t, as defined in clause 13 of [ITU-T G.808.1], shall not exceed 50 ms for a protection span length that does not exceed 1200 km.

7 Protection group commands

7.1 End-to-end commands and states

This clause describes commands that apply to the protection group as a whole. When ~~an~~ APS is present, these commands are signalled to the far end of the connection. In bidirectional switching, these commands affect the bridges and selectors at both ends.

Lockout of protection – This command prevents a normal traffic signal from being selected from the protection transport entity. This effectively disables the protection group. An extra traffic signal, if present on the protection transport entity, is dropped.

Force switch normal traffic signal #n to protection – Forces normal traffic signal #n to be selected from the protection transport entity after the required bridge is present.

Force switch null signal – For 1:n architectures, it switches the null signal to the protection transport entity, unless an equal or higher priority switch command is in effect. A normal traffic signal present on the protection transport entity is transferred to and selected from its working transport entity. For 1+1 architectures, it selects the normal traffic signal from the working transport entity.

Force switch extra traffic signal – It switches the extra traffic signal to the protection transport entity, unless an equal or higher priority switch command is in effect. A normal traffic signal present on the protection transport entity is transferred to and selected from its working transport entity.

Manual switch normal traffic signal #n to protection – In the absence of a failure of a working or protection transport entity, forces a normal traffic signal #n to be selected from the protection transport entity after the required bridge is present.

Manual switch null signal – For 1:n architectures, it switches the null signal to the protection transport entity, unless a fault condition exists on other entities or an equal or higher priority switch command is in effect. A normal traffic signal present on the protection transport entity is transferred to and selected from its working transport entity. For 1+1 architectures, it selects the normal traffic signal from the working transport entity.

Manual switch extra traffic signal – It switches extra traffic signal to the protection transport entity, unless a fault condition exists on other entities or an equal or higher priority switch command is in effect. A normal traffic signal present on the protection transport entity is transferred to and selected from its working transport entity.

Wait-to-restore normal traffic signal #n – In revertive operation, after the clearing of an SF or SD on a working transport entity #n, maintains a normal traffic signal #n as selected from the protection transport entity until a Wait-to-Restore timer expires. If the timer expires prior to any other event or command, the state will be changed to Nno Rrequest (NR). This is used to prevent frequent operation of the selector in the case of intermittent failures.

Exercise signal #n – Exercise of the APS protocol. The signal is chosen so as not to modify the selector.

Do not revert normal traffic signal #n – In non-revertive operation, this is used to maintain a normal traffic signal #n selected from the protection transport entity.

No request – All normal traffic signals are selected from their corresponding working transport entities. The protection transport entity carries either the null signal, extra traffic, or a bridge of the single normal traffic signal in a 1+1 protection group.

Clear – Clears the active near-end Lockout of Protection, Forced Switch, Manual Switch, WTR state, or Exercise command.

7.2 Local commands

These commands apply only to the near-end of the protection group. When an APS is present, they have not been signalled to the far end via the APS channel.

Freeze – Freezes the state of the protection group. Until the freeze is cleared, additional near-end commands are rejected. Condition changes and received APS bytes are ignored. When the Freeze command is cleared, the state of the protection group is recomputed based on the condition and received APS bytes.

Clear freeze

Lockout normal traffic signal #n from protection – Prevents normal traffic signal #n from being selected from the protection transport entity. Commands for normal traffic signal #n will be rejected. SF or SD will be ignored for normal traffic signal #n. In bidirectional 1:n switching, remote bridge requests for normal traffic signal #n will still be honoured to prevent protocol failures. As a result, a normal traffic signal must be locked out from protection at both ends to prevent it being selected from the protection transport entity as a result of a command or failure at either end. Multiple of these commands may coexist for different normal traffic signals.

Clear lockout normal traffic signal #n from protection

8 Protection architectures

In a linear protection architecture, protection switching occurs at the two distinct endpoints of a protected trail or protected subnetwork connection. Between these endpoints, there will be both "working" and "protection" transport entities.

For a given direction of transmission, the "head-end" of the protected signal is capable of performing a bridge function, which will place a copy of a normal traffic signal onto a protection transport entity when required. The "tail-end" will perform a selector function, where it is capable of selecting a normal traffic signal either from its usual working transport entity, or from a protection transport entity. In the case of bidirectional transmission, where both directions of transmission are protected, both ends of the protected signal will normally provide both bridge and selector functions.

The following architectures are possible:

1+1 – In a 1+1 architecture, a single normal traffic signal is protected by a single protection transport entity. The bridge at the head-end is permanent. Switching occurs entirely at the tail-end.

1:n – In a 1:n architecture, 1 or more normal traffic signal(s) are protected by a single protection transport entity. The bridge at the head-end is not established until a protection switch is required. In the case where n > 1, it cannot be known which of the normal traffic signals should be bridged onto the protection transport entity, until a defect is detected on one of the protected signals. 1:n architectures are capable of carrying an extra (low priority, pre-emptable) traffic signal on the protection transport entity when it is not being used to protect any normal traffic signal. A 1:n architecture can be used even for n = 1 (1:1). This might be chosen over the simpler 1+1 architecture (which requires no head-end actions of the protection algorithm) since 1:1 is capable of carrying extra traffic, where 1+1 is not.

m:n – In this architecture, m protection transport entities are used to protect n working transport entities. This is for further study.

With the assumption of a larger APS channel, the coding for the entity number "n" will use a full byte rather than the few bits in S~~s~~ynchronous D~~d~~igital H~~h~~ierarchy (SDH). Two of the 256 values are reserved: 0 is used to indicate a null signal or the protection transport entity and 0xFF (255) is used to indicate extra traffic.

The architecture at each end of the connection must match.

8.1 Unidirectional and bidirectional switching

In the case of bidirectional transmission, it is possible to choose either unidirectional or bidirectional switching. With unidirectional switching, the selectors at each end are fully independent. With bidirectional switching, an attempt is made to coordinate the two ends so that both have the same bridge and selector settings, even for a unidirectional failure. Bidirectional switching always requires an APS and/or ~~p~~Protection C~~c~~ommunication C~~c~~hannel (PCC) to coordinate the two endpoints.

Unidirectional switching can protect two unidirectional failures in opposite directions on different entities.

8.2 Need for an APS/PCC channel

The only switching type that does not require an APS and/or PCC channel is 1+1 unidirectional switching. With a permanent bridge at the head-end and no need to coordinate selector positions at the two ends, the tail-end selector can be operated entirely according to defects and commands received at the tail-end.

Bidirectional switching always requires an APS channel. 1:n unidirectional switching requires an APS channel to coordinate the head-end bridge with the tail-end selector.

8.3 Revertive and non-revertive switching

In revertive operation, traffic is restored to the working transport entities after a switch reason has cleared. In the case of clearing a command (e.g., Forced Switch), this happens immediately. In the case of clearing of a defect, this generally happens after the expiry of a "Wait-to-Restore" timer, which is used to avoid chattering of selectors in the case of intermittent defects.

In non-revertive operation, normal traffic is allowed to remain on the protection transport entity even after a switch reason has cleared. This is generally accomplished by replacing the previous switch request with a "D~~d~~o N~~n~~ot R~~r~~evert (DNR)" request, which is low priority.

1+1 protection is often provisioned as non-revertive, as the protection is fully dedicated in any case and this avoids a second "glitch" to the traffic. There may, however, be reasons to provision this to be revertive (e.g., so that the traffic uses the "short" direction around a ring except during failure conditions. Certain operator policies also dictate revertive operation even for 1+1).

Usually, 1:n protection is revertive. Certainly in the case where an extra traffic signal is carried on the protection transport entity, the operation would always be revertive so that the pre-empted extra traffic signal can be restored. It is certainly possible to define the protocol in a way that would permit non-revertive operation for 1:n protection, but the expectation is that it is better to revert and glitch the traffic when the working transport entity is repaired than when some other entity in the group fails that requires use of the protection transport entity to carry a different normal traffic signal.

In general, the choice of revertive/non-revertive will be the same at both ends of the protection group. However, a mismatch of this parameter does not prevent interworking – it just would be peculiar for one side to go to W~~w~~ait-to-R~~r~~estore (WTR) for clearing of switches initiated from that side, while the other goes to DNR for its switches. See also clause 8.4.

8.4 Provisioning mismatches

With all of the options for provisioning of protection groups, there are opportunities for mismatches between the provisioning at the two ends. These provisioning mismatches take one of several forms:

– Mismatches where proper operation is not possible.

– Mismatches where one or both sides can adapt their operation to provide a degree of interworking in spite of the mismatch.

– Mismatches that do not prevent interworking. An example is the revertive/non-revertive mismatch discussed in clause 9.4.

Not all provisioning mismatches can be conveyed and detected by information passed through the APS channel. With a potential for up to 254 working transport entities in a 1:n protection group, there are simply too many combinations of valid entity numbers to easily provide full visibility of all the configuration options. What is desirable, however, is to provide visibility for the middle category, where the sides can adapt their operation to interwork in spite of the mismatch. For example, an equipment provisioned for bidirectional switching could fall back to unidirectional switching to allow interworking. An equipment provisioned for 1+1 switching with an APS channel could fall back to operate in 1+1 unidirectional switching without an APS channel. The user could still be informed of the provisioning mismatch, but a level of protection could still be provided by the equipment.

NOTE – To prevent APS protocol mismatch in provisioning of interfaces in respect to configuration of linear and other protection mechanisms, proper Ttrail Ttrace Iidentifier (TTI) management should be used to detect such situation.

8.5 Overview of protection architectures for OTN linear protection

Table 8-1 provides an overview of the linear OTN protection types which are supported by the specifications in this Recommendation. It provides information of the possible supported protection architectures versus the related supporting switching types, APS channel used, related server layers and protected entities. It should be noted that the compound link group protection as specified in [ITU-T G.808.1] includes support for unprotected service. This [ITU-T G.808.1] specification needs to be considered for the compound link group protection classes.

Table 8-1 – Overview of linear OTN protection architectures and related monitoring

Protection architecture	Switching type	Protection subclass and monitoring	ODU entities for protection switching, individual/ group	APS channel used and MFAS in bits 6-8	Server layer of protected entity	Protection switched entity	Trigger criteria used
1+1	Unidir	SNC/I	Individual	No	One HO ODUk or one OTUk or one ODUCn	ODUkP or ODUkT	ODU SSF/SSD
1+1	Bidir	SNC/I	Individual	111	One OTUk or one HO ODUk or one ODUCn	ODUkP or ODUkT	ODU SSF/SSD
1:n	Bidir	SNC/I	Individual	111	One OTUk or one HO ODUk or one ODUCn	ODUkP or ODUkT	ODU SSF/SSD
1+1	Unidir	SNC/Ne	Individual	No	One or more HO ODUk and/or OTUk and/or ODUCn	ODUkP	ODU TSF/TSD
1+1	Bidir	SNC/Ne	Individual	000	One or more HO ODUk and/or OTUk and/or ODUCn	ODUkP	ODU TSF/TSD

Table 8-1 – Overview of linear OTN protection architectures and related monitoring

Protection architecture	Switching type	Protection subclass and monitoring	ODU entities for protection switching, individual/ group	APS channel used and MFAS in bits 6-8	Server layer of protected entity	Protection switched entity	Trigger criteria used
1+1	Unidir	SNC/Ns	Individual[4]	No	One or more HO ODUk and/or OTUk and/or ODUCn	ODUkT	ODU TSF/TSD
1+1	Bidir	SNC/Ns	Individual[4]	001-110	One or more HO ODUk and/or OTUk and/or ODUCn	ODUkT	ODU TSF/TSD
1+1	Unidir	SNC/S	Individual[4]	No	One or more HO ODUk and/or OTUk and/or ODUCn	ODUkT or ODUkP	ODUkT SSF/SSD
1+1	Bidir	SNC/S	Individual[4]	001-110	One or more HO ODUk and/or OTUk and/or ODUCn	ODUkT or ODUkP	ODUkT SSF/SSD
1:n	Bidir	SNC/S	Individual[4]	001-110	One or more HO ODUk and/or OTUk and/or ODUCn	ODUkT or ODUkP	ODUkT SSF/SSD
1+1	Unidir	CL-SNCG/I	Group	No	One HO ODUk or one ODUCn	LO ODU	HO ODUkP or ODUCnP SSF/SSD
1+1	Bidir	CL-SNCG/I	Group	HO 000 ODUCn 000	One HO ODUk or one ODUCn	LO ODU	HO ODUkP or ODUCnP SSF/SSD
1:1	Bidir	CL-SNCG/I	Group	HO 000 ODUCn 000	One HO ODUk or one ODUCn	LO ODU	HO ODUkP or ODUCnP SSF/SSD

Table 8-1 – Overview of linear OTN protection architectures and related monitoring

<table>
<tr><th>Protection architecture</th><th>Switching type</th><th>Protection subclass and monitoring</th><th>ODU entities for protection switching, individual/ group</th><th>APS channel used and MFAS in bits 6-8</th><th>Server layer of protected entity</th><th>Protection switched entity</th><th>Trigger criteria used</th></tr>
<tr><td colspan="8">NOTE 1 – Bidir SNC/N, is supported but care should be taken in case of nested protection schemes as an APS channel may be used by more than one protection scheme and/or protection scheme instance. It is recommended to use 1+1 bidir SNC/S instead.
NOTE 2 – CL-SNCG/I can assign all Normal signal to the Na subgroup and leave the Nb subgroup empty.
NOTE 3 – The equipment models and required processes of the various architectures are given in the related subclauses of clause 14.1 of [ITU-T G.798].
NOTE 4 – The SNC/S architecture may be implemented when there is HO/LO muxing with "emulation" of line switching by switching all contained LO ODU connections. Examples are given in [ITU-T G.798.1].</td></tr>
</table>

9 APS protocol

9.1 APS channel format

An APS channel is carried over the first three bytes of the APS/PCC field of the ODUk overhead. The fourth byte of the APS/PCC field is reserved. Eight independent APS channels are available to support protection at the ODUkP, the six ODUkT (TCM) levels and one level of ODUk SNC/I protection as defined in clause 15.8.2.4 of [ITU-T G.709].

The format of the four APS bytes themselves within each frame is defined in Figure 9-1. The field values for the APS channels are defined in Table 9-1.

<table>
<tr><td colspan="8">1</td><td colspan="8">2</td><td colspan="8">3</td><td colspan="8">4</td></tr>
<tr><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td></tr>
<tr><td colspan="4">Request/ state</td><td colspan="4">Protection type</td><td colspan="8">Requested Signal</td><td colspan="8">Bridged Signal</td><td colspan="8">Reserved</td></tr>
<tr><td colspan="4"></td><td>A</td><td>B</td><td>D</td><td>R</td><td colspan="8"></td><td colspan="8"></td><td colspan="8"></td></tr>
</table>

Figure 9-1 – APS channel format

Table 9-1 – Field values for APS channels

Field	Value	Description
Request/State	1111	Lockout of protection (LoP)
	1110	Forced switch (FS)
	1100	Signal fail (SF)
	1010	Signal degrade (SD)
	1000	Manual switch (MS)
	0110	Wait-to-restore (WTR)
	0100	Exercise (EXER)
	0010	Reverse request (RR)
	0001	Do not revert (DNR)
	0000	No request (NR)

Table 9-1 – Field values for APS channels

Field		Value	Description
		Others	Reserved for future international standardization
Protection Type	A	0	No APS channel
		1	APS channel
	B	0	1+1 (permanent bridge)
		1	1:n (no permanent bridge)
	D	0	Unidirectional switching
		1	Bidirectional switching
	R	0	Non-revertive operation
		1	Revertive operation
Requested Signal		0	Null signal
		1-254	Normal traffic Signal 1-254
		255	Extra traffic signal
Bridged Signal		0	Null signal
		1-254	Normal traffic Signal 1-254
		255	Extra traffic signal

9.2 Transmission and acceptance of APS protocol

The APS/PCC protocol is transmitted via the protection transport entity. Although it may also be transmitted identically on working transport entities, receivers should not assume so and should have the capability to ignore this information on the working transport entities.

For each of the eight levels, an independent acceptance process shall be performed. As the APS protocol is carried via the first three of the four APS/PCC bytes, only these three bytes are taken into account for the acceptance process. A new APS protocol value shall be accepted if an identical value is received in these three bytes of a given level three times consecutively.

NOTE 1 – If no errors occur, acceptance is reached after 2360 µs (ODU0), 1175 µs (ODU1), 298 µs (ODU2), 72 µs (ODU3), 28 µs (ODU4), 2936832/ODUflex-bitrate µs (ODUflex).

NOTE 2 – Since the fourth byte of the APS message is 'reserved', it has not to be taken into account for the acceptance process of APS bytes.

9.3 Request type

The request types that may be reflected in the APS bytes are the "standard" types traditionally supported by protection switching for SONET and SDH. These requests reflect the highest priority condition, command, or state (see Tables 9-2 and 9-3). In the case of unidirectional switching, this is the highest priority value determined from the near-end only. In bidirectional switching, the sent Request/State shall indicate:

a) a reverse request if;

I. the remote request is of higher priority, or if

II. ~~or if~~ the requests are of the same level (and are higher priority than a no request / do not revert) and the sent Request/State already indicates reverse request, or if

III. the requests are of the same level (and are higher priority than a no request / do not revert) and the sent Request/State byte does not indicate reverse request and the remote request indicates a lower entity ID;

b) the local request in all other cases.

Table 9-2 – Request/state priorities with APS protocol

Request/state	Priority
Lockout for Protection (LoP)	1 (highest)
Signal Fail (SF) – protection	2 (see clause 9.9)
Forced Switch (FS)	3
Signal Fail (SF) – working	4
Signal Degrade (SD)	5
Manual Switch (MS)	6
Wait-to-Restore (WTR)	7
Exercise (EXER)	8
Reverse Request (RR)	9
Do Not Revert (DNR)	10
No Request (NR)	11 (lowest)

Table 9-3 – Request/state priorities without APS protocol

Request/state	Priority
Lockout for Protection (LoP)	1 (highest)
Forced Switch (FS)	2
Signal Fail (SF)	3
Signal Degrade (SD)	4
Manual Switch (MS)	5
Wait-to-Restore (WTR)	6
Do Not Revert (DNR)	7
No Request (NR)	8 (lowest)

9.4 Protection types

The valid protection types are:

000x 1+1 unidirectional, no APS

100x 1+1 unidirectional w/APS

101x 1+1 bidirectional w/APS

110x 1:n unidirectional w/APS

111x 1:n bidirectional w/APS

The values are chosen such that the default value (all zeros) matches the only type of protection that can operate without APS (1+1 unidirectional).

Note that 010x, 001x and 011x are invalid since 1:n and bidirectional require APS.

If the "B" bit mismatches, the selector is released since 1:n and 1+1 are incompatible. This will result in an alarm. Refer to clauses 6.2.7.1.1 and 14.1.1.1 of [ITU-T G.798].

Provided the "B" bit matches:

If the "A" bit mismatches, the side expecting APS will fall back to 1+1 unidirectional switching without APS.

NOTE 1 – In the case where a node does not support the APS channel, an all-0's pattern will be present in the APS/PCC field as specified in clause 15 of [ITU-T G.709].

If the "D" bit mismatches, the bidirectional side will fall back to unidirectional switching.

If the "R" bit mismatches, one side will clear switches to "WTR" and the other will clear to "DNR". The two sides will interwork and the traffic is protected.

NOTE 2 – Each side signals always its maximum capabilities in the protection type field even if it falls back to operate with less capabilities (i.e., a side which supports bidirectional switching falls back to operate as unidirectional switch in case of interworking with a side that supports unidirectional switching only, but still signals "1" in the "D" bit).

9.5 Requested signal

This indicates the signal that the near-end requests to be carried over the protection transport entity. For NR, this is either the Null Signal (0) or Extra Traffic (255). For LoP, this can only be the Null Signal (0). For Exercise, this can be the Null Signal (0) or the Extra Traffic Signal (255) when Exercise replaces NR, or the number of a normal traffic signal in the case where Exercise replaces DNR. For SF or SD, this will be the number of a normal traffic signal, or the Null Signal (0) to indicate that protection is failed or degraded. For all other requests, this will be the number of the normal traffic signal requested to be carried over the protection transport entity.

9.6 Bridged signal

This indicates the signal that is bridged onto the protection transport entity. For 1+1 protection, this should always indicate Normal traffic Signal 1, accurately reflecting the permanent bridge. This allows a 1-phase rather than a 2 or 3-phase switch in the case of 1+1 architecture. For 1:n protection, this will indicate what is actually bridged to the protection transport entity (either the Null Signal (0), Extra Traffic (255), or the number of a normal traffic signal). This will generally be the bridge requested by the far end.

If for the 1:N bidirectional architecture for the protection transport entity a local SF condition is present the bridge is released.

If for a 1:N unidirectional architecture, the protection transport entity is found in a local SF condition, the bridge is frozen.

9.7 Control of bridge

In 1+1 architectures, the normal traffic signal is permanently bridged to protection. The normal traffic signal number "1" will always be indicated in the bridged signal field of the APS channel.

In 1:n architectures, the bridge will be set to the one indicated by the "Requested Signal" field of the incoming APS channel. Once the bridge has been established, this will be indicated in the "Bridged Signal" field of the outgoing APS channel.

9.8 Control of selector

In 1+1 unidirectional architectures (with or without APS), the selector is set entirely according to the highest priority local request. This is a single-phase switch.

In 1+1 bidirectional architectures, the normal traffic signal will be selected from the protection transport entity when the outgoing "Requested Signal" and the incoming "Bridged Signal" both indicate Normal traffic Signal "1" (The incoming "Bridged Signal" should always indicate "1" in this architecture). The far end does not switch until the APS bytes indicating that a bidirectional switch is initiated by the near-end arrives. This is also a single-phase switch.

In 1:n uni- or bidirectional architectures, a normal traffic signal "n" or extra traffic signal 255 will be selected from the protection transport entity when the same number "n" (or 255) appears in both the outgoing "Requested Signal" and the incoming "Bridged Signal" fields. This generally results in a three-phase switch.

9.9 Signal Fail of the protection transport entity

Signal Fail on the protection transport entity is higher priority than any defect that would cause a normal transport signal to be selected from the protection transport entity. For the case an APS signal is in use, a SF on the protection transport entity (over which the APS signal is routed) has priority over Forced Switch. A Lockout command has higher priority than SF. During failure conditions, lockout status shall be kept active.

9.10 Equal priority requests

In general, once a switch has been completed due to a request, it will not be overridden by another request of the same priority (first come, first served behaviour). When equal priority requests occur simultaneously, the conflict is resolved in favour of the request with the lowest entity number. In bidirectional switching, a request received over the APS channel with a lower entity number will always override an identical priority local request with a higher entity number. Equal priority requests for the same entity number from both sides of a bidirectional protection group are both considered valid, and equivalent to a received "RR" from a near-end processing standpoint.

9.11 Command acceptance and retention

The commands CLEAR, LoP, FS, MS and EXER are accepted or rejected in the context of previous commands, the condition of the working and protection transport entities in the protection group and (in bidirectional switching only) the received APS bytes.

The CLEAR command is only valid if a near-end LoP, FS, MS, or EXER command is in effect or if a WTR state is present at the near-end and rejected otherwise. This command will remove the near-end command or WTR state, allowing the next lower priority condition or (in bidirectional switching) APS request to be asserted.

Other commands are rejected unless they are higher priority than the previously existing command, condition, or (in bidirectional switching) APS request. If a new command is accepted, any previous, lower priority command that is overridden is forgotten. If a higher priority command overrides a lower priority condition or (in bidirectional switching) APS request, that other request will be reasserted if it still exists at the time the command is cleared.

If a command is overridden by a condition or (in bidirectional switching) APS request, that command is forgotten.

9.12 Hold-off timer

In order to coordinate timing of protection switches at multiple layers or across cascaded protection domains, a hold-off timer may be required. The purpose is to allow either a server layer protection switch to have a chance to fix the problem before switching at a client layer, or to allow an upstream protection domain to switch before a downstream domain (e.g., to allow an upstream ring to switch before the downstream ring in a dual node interconnect configuration so that the switch occurs in the same ring as the failure).

Each protection group should have a provisionable hold-off timer. The suggested range and values are 0, 20 ms and 100 ms to 10 seconds in steps of 100 ms (accuracy of ±5 ms as per [ITU-T G.808.1]).

The operation of the hold-off timer uses the "peek twice" method specified in SDH standards. Specifically, when a new defect or more severe defect occurs (new SD or SF, or SD becoming SF), this event will not be reported immediately to protection switching if the provisioned hold-off timer value is non-zero. Instead, the hold-off timer will be started. When the hold-off timer expires, it will be checked whether a defect still exists on the trail that started the timer. If it does, that defect will be reported to protection switching. The defect need not be the same one that started the timer.

9.13 Exercise operation

Exercise is a command to test if the APS channel is operating correctly. It is lower priority than any "real" switch request. It is only valid in bidirectional switching, since this is the only place where you can get a meaningful test by looking for a response.

Exercise command shall issue the command with the same requested and bridged entity numbers of the NR or DNR request that it replaces. The valid response will be an RR with the corresponding requested and bridged entity numbers. To allow the RR to be detected, the standard response to DNR should be DNR rather than RR. When the exercise command is cleared, it will be replaced with NR if the requested entity number is 0 or 255 and DNR for any normal traffic signal number 1 to 254.

NOTE – Exercise operation for OTN has been defined differently from exercise operation defined for SDH.

9.14 APS channel alarming

"Failure of Protocol" situations for groups requiring APS are as follows:

– Fully incompatible provisioning (the "B" bit mismatch), described in clause 9.4.

– Lack of response to a bridge request for > 1 s as defined for dFOP-NR in clause 6.2.7.1.2 [ITU-T G.798] for the following protection types.

– For 1+1 bidirectional, mismatch in sent "*Requested Entity*" and received "*Requested Entity*".

– For 1:n unidirectional, mismatch in sent "*Requested Entity*" and received "*Bridged Entity*".

– For 1:n bidirectional, mismatch in sent "*Requested Entity*" and received "*Bridged Entity*" as well as in sent "*Requested Entity*" and received "*Requested Entity*".

If an unknown request or a request for an invalid entity number is received, it will be ignored. It will be up to the far end to alarm the non-response from the near-end.

If for a 1:N unidirectional architecture a SF request for the Null Signal is received via the APS channel, a mismatch in sent "Requested Entity" and received "Bridged Entity" shall not result in a "Failure of Protocol".

9.15 SF persistency timer

SF persistency timers can be used to coordinate timing of protection switches across cascaded ODUk SNC/S protection domains. This timer prevents a downstream ODUk SNC/S protection domain to switch either due to the protection switches of any upstream protection domain(s) in cascaded configuration, or due to a signal fail condition at the unprotected ingress port.

Per transport entity an active status of Signal Fail (e.g., SF = ODUkT_AI_TSF) shall only be reported to the protection control process (or to a sub-sequent hold-off timer process) if this status has been found permanently present at input of the related persistency filter for the duration of a verification interval. The duration of verification interval should be no more than 10 ms.

NOTE – The SF persistency time is considered to be part of the T2 time as described in [ITU-T G.808.1], which should be understood as "SF persistency and hold-off time, T2".

Appendix I

Examples of operation

(This appendix does not form an integral part of this Recommendation.)

I.1 1+1 unidirectional switching

APS may or may not be present. Even if APS is not present, the bridge is assumed to be permanent~~,~~; thus ~~so~~ switches are performed immediately according to the local request. The APS bytes, if present, are informational only and do not control the operation of the protection group. If they are present, an item of equipment may allow a query for the far end state.

This example shows overlapping SF and SD requests from opposite sides. For illustration, the example in Figure I.1 shows mismatched provisioning with side A being non-revertive and side B being revertive.

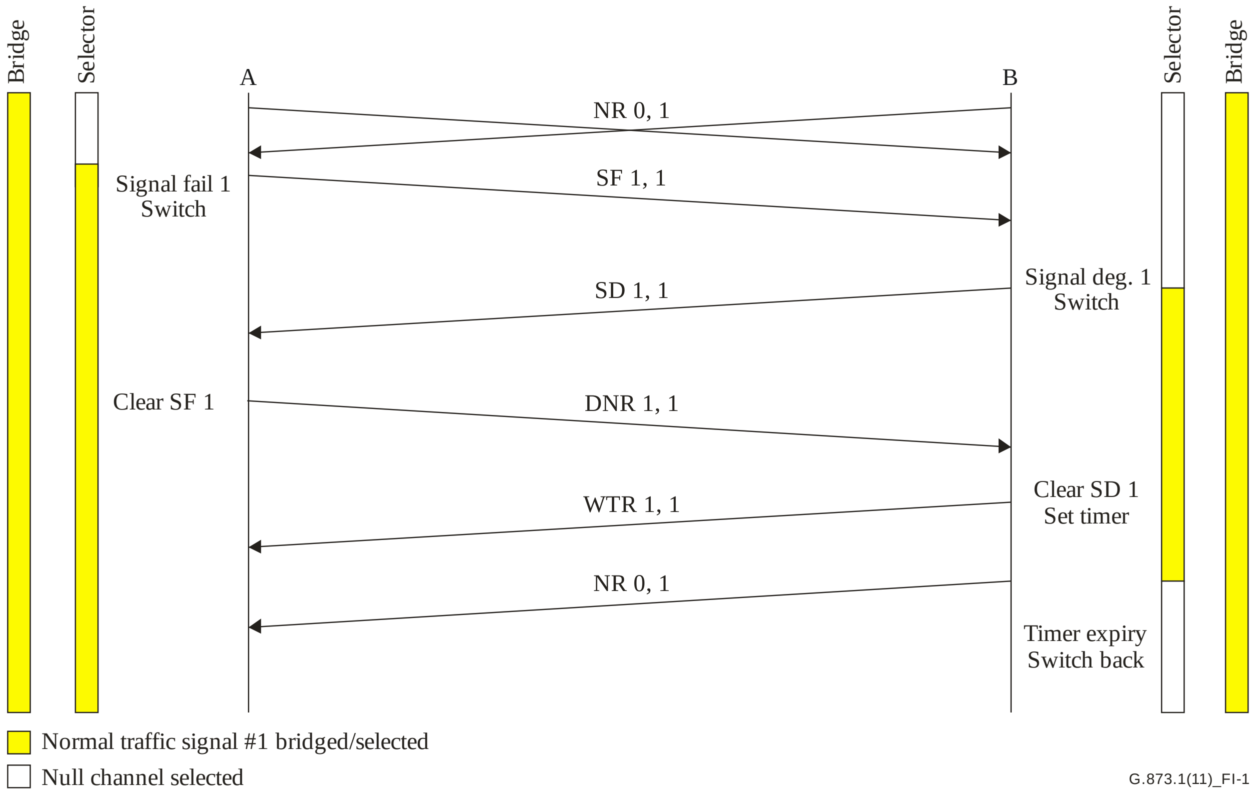
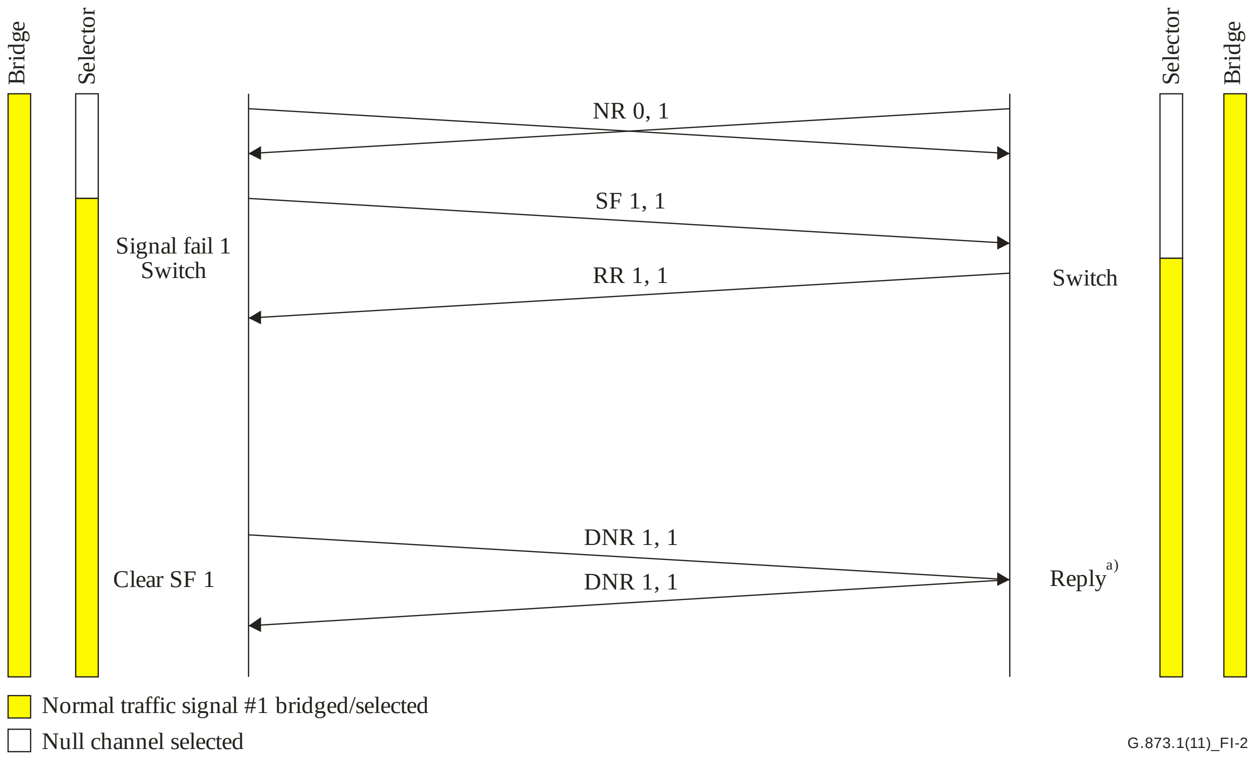


Figure I.1 – Example APS message flow for 1+1 unidirectional switching

I.2 1+1 bidirectional switching

The example in Figure I.2 illustrates a 1+1, bidirectional, non-revertive switch. Because the permanent bridge is indicated in the APS bytes from the start, the switch can be a single-phase instead of two or three-phase.



a) Historically, DNR was acknowledged with RR. Here, answering DNR with DNR makes no fundamental difference in the states of the two sides and it allows for a meaningful exercise implementation.

Figure I.2 – Example APS message flow for 1+1 bidirectional switching

I.3 1:n bidirectional switching

Figure I.3 shows an example of 1:n bidirectional switching with extra traffic. What is illustrated is the case where an SD on working #2 is pre-empted by an SF on working #3.

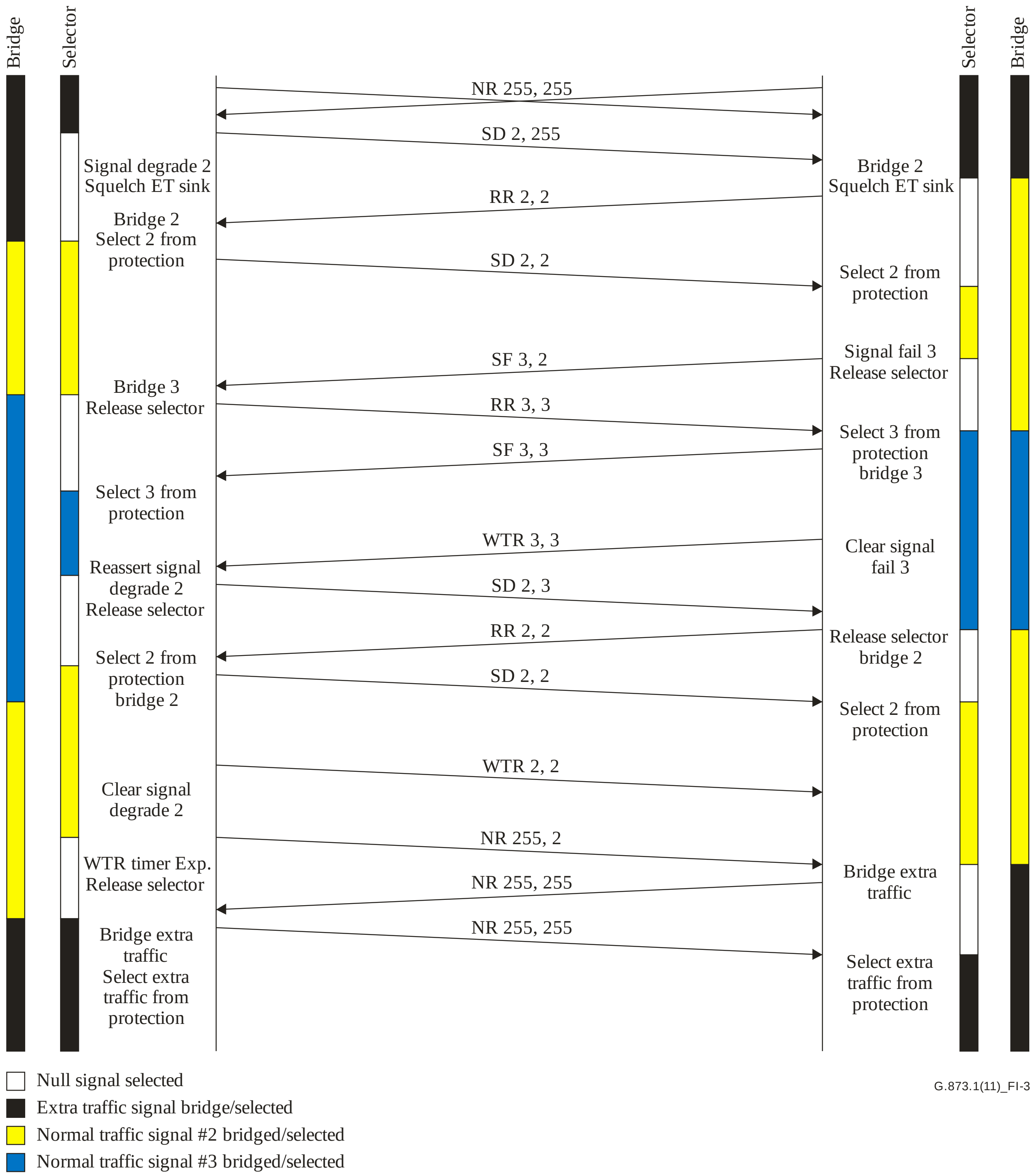


Figure I.3 – Example APS message flow for 1:n bidirectional switching

I.4 Exercise command operation

The Exercise command tests whether the far end will respond to an APS channel request in bidirectional switching without operating the selector. This command is low priority so as not to interfere with the actual operation of the protection group. It is only valid when the current request is NR or DNR, as it is lower in priority than all other requests.

Figures I.4, I.5, I.6 and I.7 give examples of the operation of the Exercise command. In all cases, neither the requested nor the bridged entity numbers are changed for the Exercise command. A successful response is receiving an "RR" with the same entity number. Note that having DNR answered with DNR provides a way to test that the Exercise command receives the appropriate RR response.

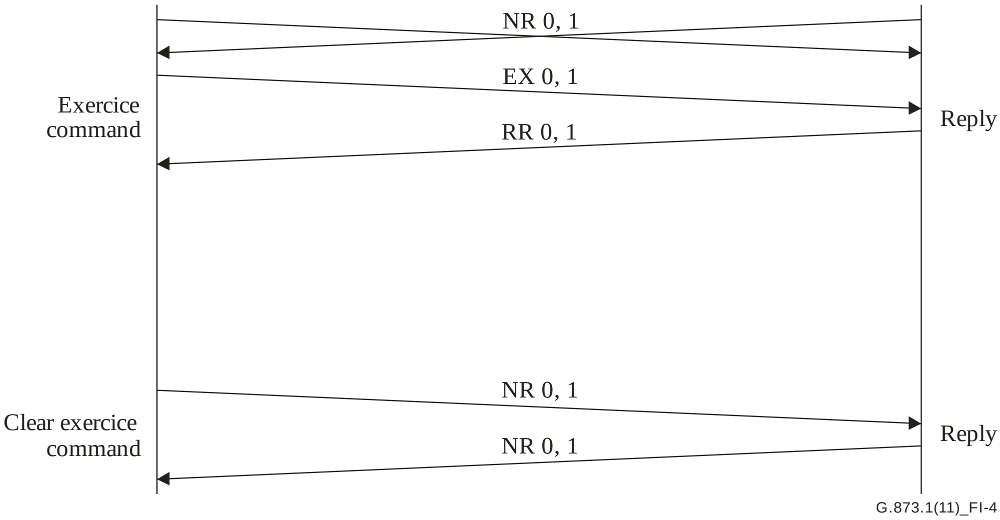


Figure I.4 – Example of Exercise command from 1+1 NR state

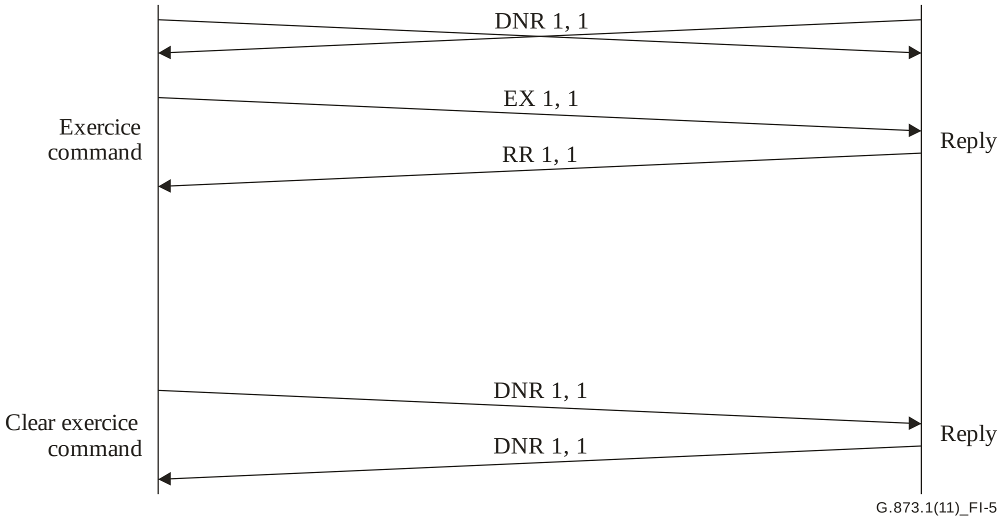


Figure I.5 – Example of Exercise command from 1+1 DNR state

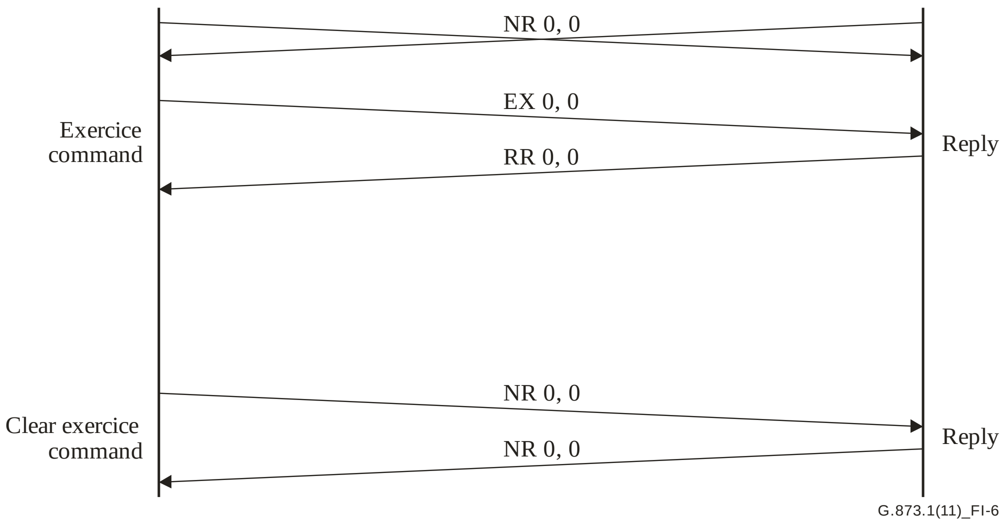


Figure I.6 – Example of Exercise command from 1:n NR state without extra traffic

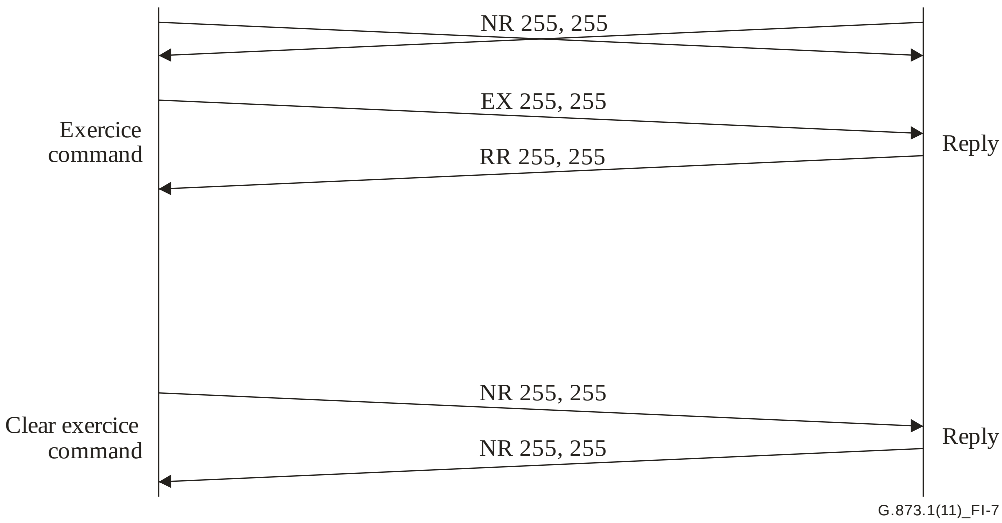


Figure I.7 – Example of Exercise command from 1:n NR state with extra traffic

Appendix II

ODUk client protection

(This appendix does not form an integral part of this Recommendation.)

II.1 Overview over protection architectures of OTN linear client protection

Table II.1 provides an overview of the linear OTN client protection types which are supported by the description in this appendix.

Table II.1 – Overview of linear OTN client protection architectures and related monitoring

Protection architec-ture	Switching type	Protection subclass and monitoring	ODU entities for protection switching, individual/ group	APS channel used and MFAS in bits 6-8	Server layer of protected entity	Protection switched entity	Trigger criteria used
1+1	Unidir	SNC/Nc	Individual	No	One or more HO ODUk and/or OTUk	LO	LO ODU TSF/TSD + LO OPU-CSF
1+1	Unidir	SNC/I	Individual	No	One LO ODUk	Client	Client_CI_CSF Client_CI_SSD
1+1	Bidir	SNC/I	Individual	LO 000	One LO ODUk	Client	Client_CI_CSF Client_CI_SSD
1:1	Bidir	SNC/I	Individual	LO 000	One LO ODUk	Client	Client_CI_CSF Client_CI_SSD

II.2 Model of client SNC/Nc protection architecture of OTN linear client protection

Figure II.1 provides the model overview of the client SNC/Nc scheme as listed in Table II.1. The protection uses the ODU connection function and the CI_SSF CI_CSF information of the ODU NIM OTN as input to the protection. This is a special version of the 1+1 ODUk SNC/N protection method in which the status of the incoming client signal as encoded in the client signal fail (CSF) indication of the optical payload unit (OPU) is used as an additional signal fail condition.

Monitoring method

Non-intrusive with client fail – Protection switching is triggered by a non-intrusive monitor of the ODUkP trail and OPUk-CSF at the tail-end of the protection group.

NOTE – This monitoring type is also intended to support protection switching in dual-root 1+1 p2mp, unidirectional switched SNC/Nc protected ODUk connections, which are deployed in content distribution applications.

Protection architecture

Dual-root 1+1 – In a dual-root 1+1 architecture, two unidirectional client signals with the same content, typically applied at different locations to the OTN, are protected. One of the client signals is carried in a working ODUk connection and the other client signal is carried in a protection ODUk connection. Switching occurs entirely at the tail-end by monitoring the ODUk and OPUk.

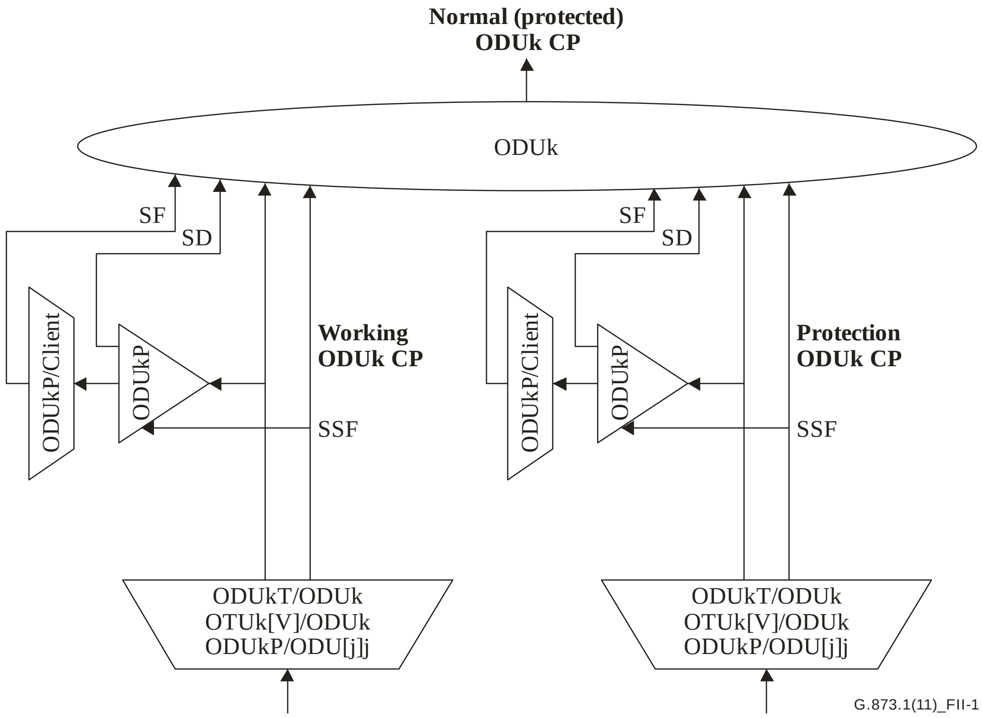


Figure II.1 – SNC/Nc protection atomic functions

Figure II.1 gives the atomic functions involved in SNC/Nc protection. The working and protection ODU_CI coming from either an OTUk[V]/ODUk_A or ODUkT/ODUk_A or ODUkP/ODUj_A function are monitored by a ODUkP and ODUkP/Client non-intrusive monitor, which provide the SF and SD protection switching criteria. The protection may rely on a particular ODUk/Client adaptation source function which is capable to activate OPUk-CSF under failure of the client signal, as for example a ODU0P/ETC3_A_So function which could be capable to activate OPU0-CSF under failure of the 1GE content stream.

II.3 Model of client SNC/I protection architectures of OTN linear client protection

Figure II.2 provides the model overview of the client SNC/I schemes as listed in Table II.1. The protection uses the client connection function external to the OTN and the OPU-CSF transport of the OTN as input to the protection.

SNC/I client protection requires that the client signal be split between two different ports in the client-to-network direction. Each port maps the client into an ODUk and the two ODUk are carried across the OTN as if they were unrelated, unprotected signals. At the far end, the two ODUks are each terminated and the client signals are recovered. One or the other client signal is transmitted, based on monitoring of the ODUk overhead (including OPU-CSF). Two different selection mechanisms are possible, as shown in Figure II.2. Option (a) uses a Y-cable and a control process that monitors the ODUkP trail termination functions to determine which one provides the better signal and controls the client termination function (srv_TT) such that only one of the two transmitters is active. Option (b) uses an external optical switch with a selector that is controlled by the ODUkP trail termination functions. The client's APS information is transported over the ODUk PM APS channel. Access to this channel is provided via an extended version of the ODUkP/CBR adaptation functions specified in [ITU-T G.798]. The extension contains support for ODUk PM APS insertion and extraction processes as illustrated in Figures II.3 and II.4.

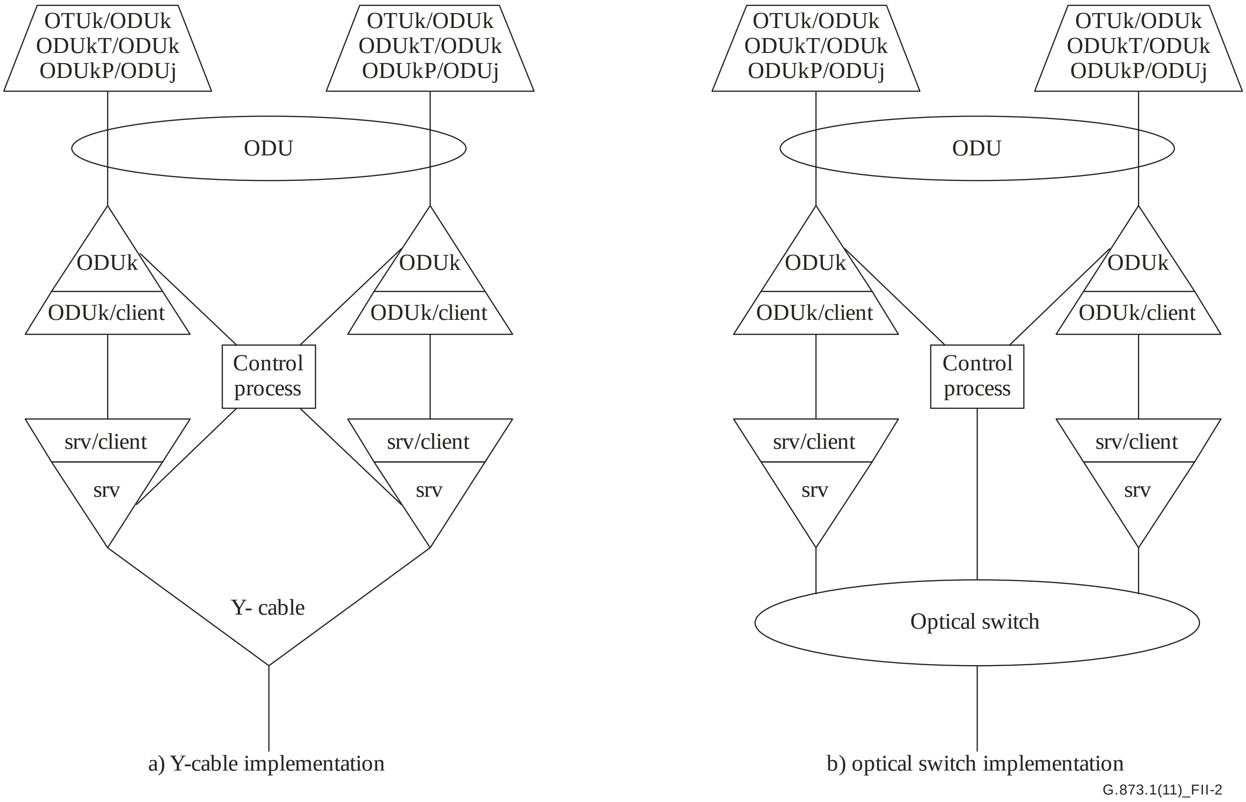


Figure II.2 – OTN client SNC/I protection models

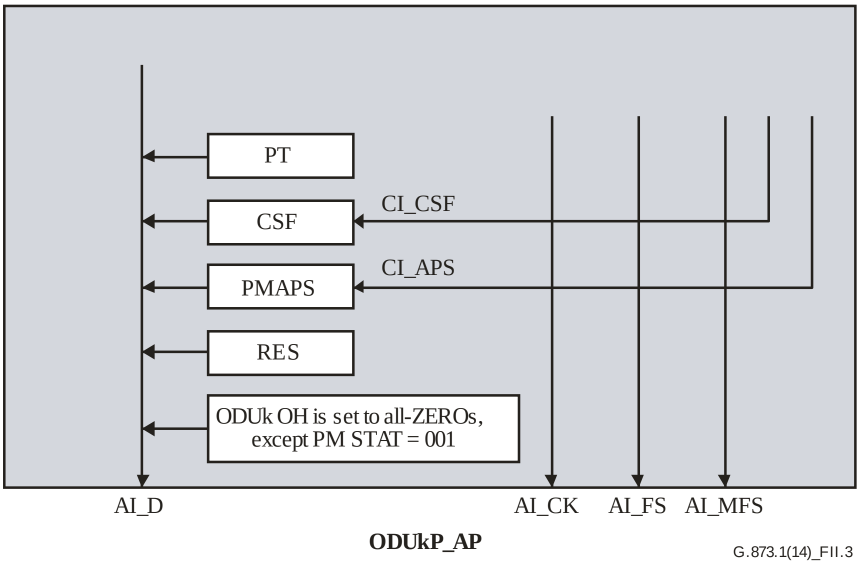


Figure II.3 – Supporting ODUk PM APS access in ODUkP/CBR adaptation source functions

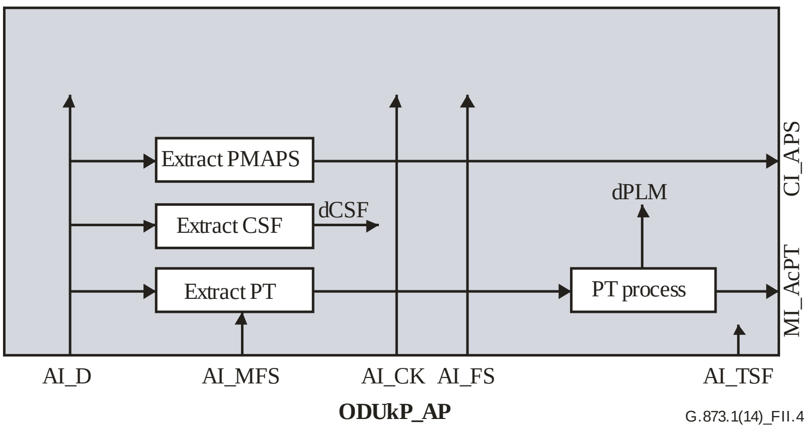


Figure II.4 – Supporting ODUk PM APS access in ODUkP/CBR adaptation sink functions

Appendix III

Media layer protection

(This appendix does not form an integral part of this Recommendation.)

III.1 Overview of media layer protection

Protection of the media layer can be provided for as OTS maintenance entity, OMS maintenance entity, OTSi or directly on the fibre through the use of a media element that includes an optical switch and the use of trail protection for the non-associated overhead (if present). The location of the optical switch within the media element and which elements of non-associated overhead are protected determine~~s~~ which type of protection is provided by a particular implementation.

This appendix describes the corresponding media layer protection schemes.

III.2 Media layer protection types

The OTS and OMS media link has been defined in clause 8.4 of [b-ITU-T G.872] and the context is shown in Figure III.1 as an example of a network with OTS and OMS OSME.

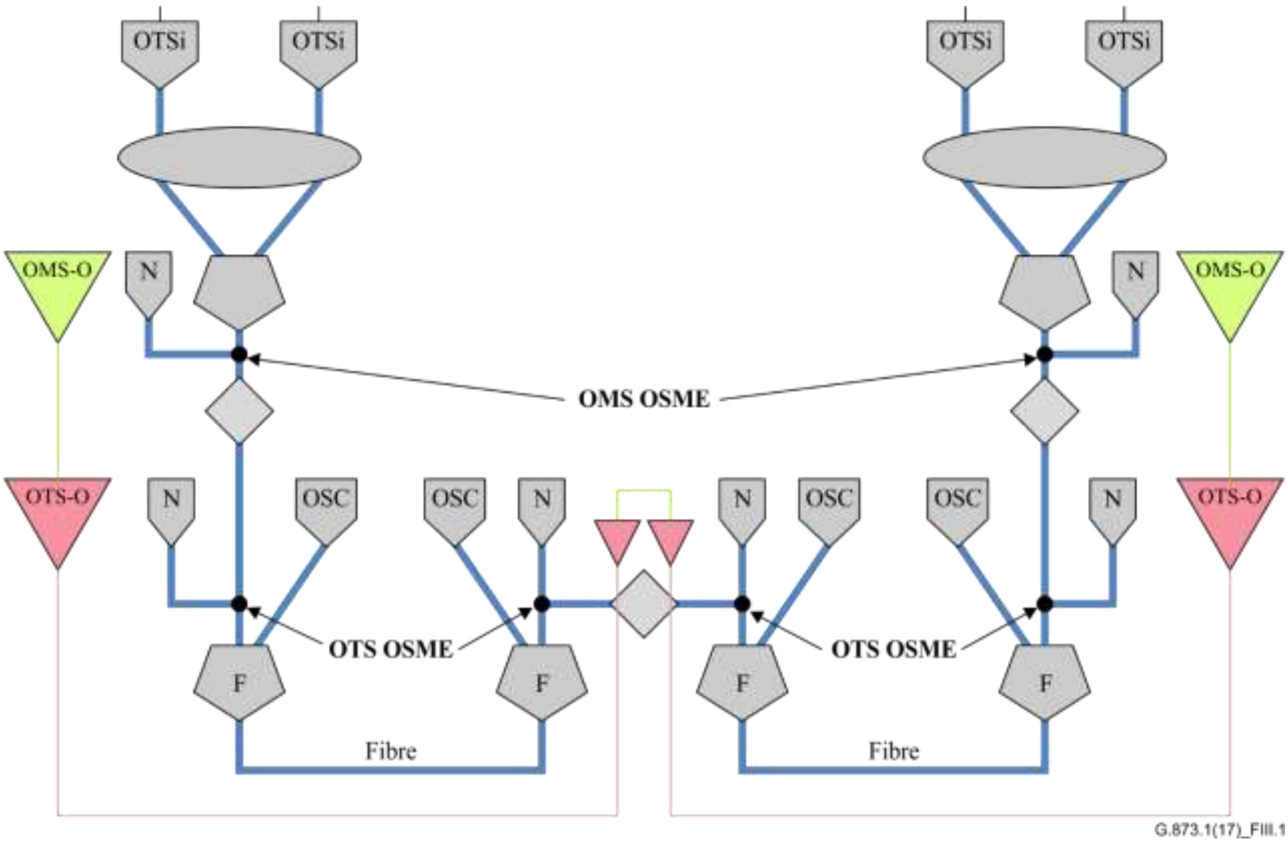


Figure III.1 – Network with OTS and OMS optical signal maintenance entities (OSME)

OTS OSME protection

A protected OTS OSME can be provided between two nodes. In this case there is a separate OSC channel for the working and protection links and there may optionally be redundant amplifiers. Trail protection is used for the OTS-O sublayer. The optical switch and OTS-O trail protection are coordinated such that they switch together. This is shown in Figure III.2.

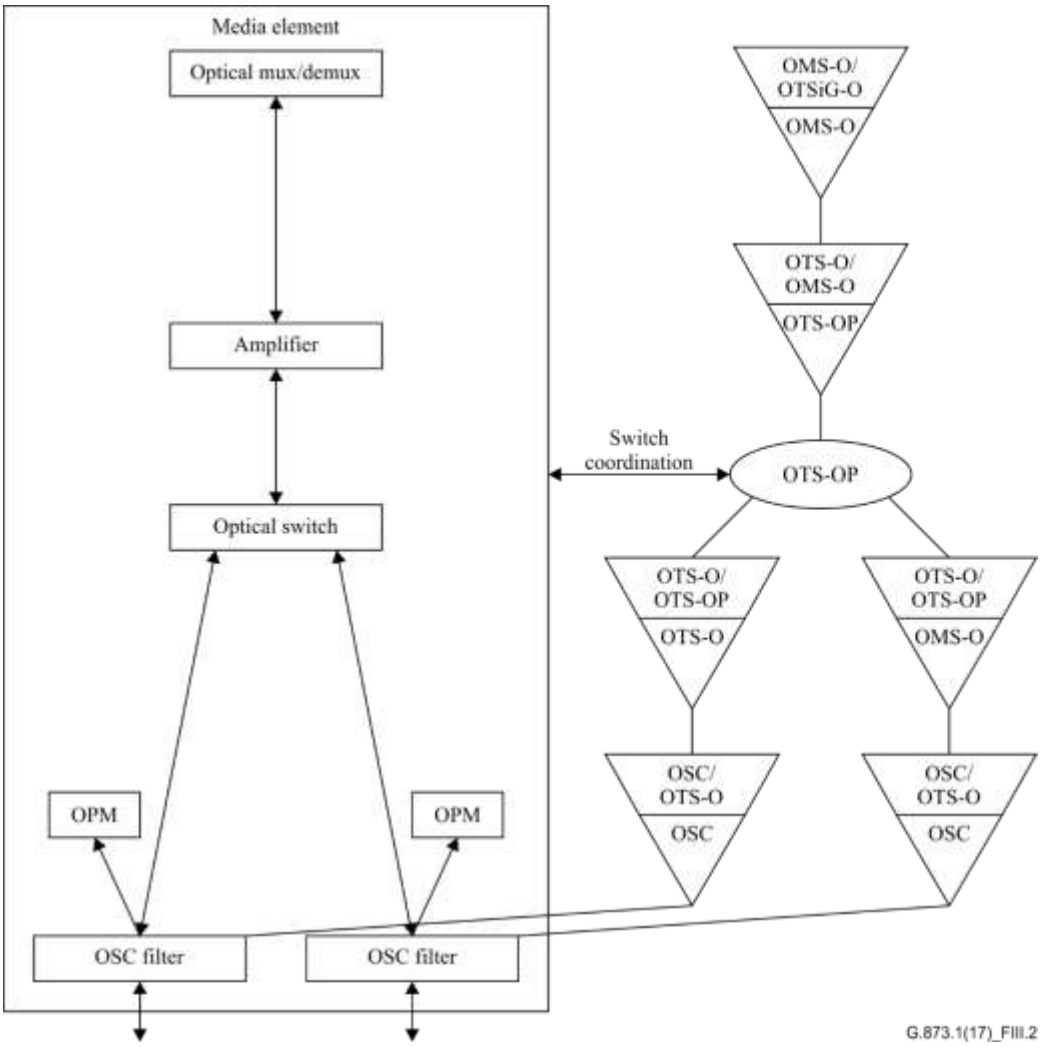


Figure III.2 – OTS OSME protection

OMS OSME protection

A protected OMS maintenance entity can be provided between two nodes. In this case there is a separate OSC channel for the working and protect links, the media element has separate amplifiers for each link and there is a separate OTS-O overhead for each link. Trail protection is used for the OMS-O sublayer. The optical switch and OMS-O trail protection are coordinated such that they switch together. This is shown in Figure III.3.

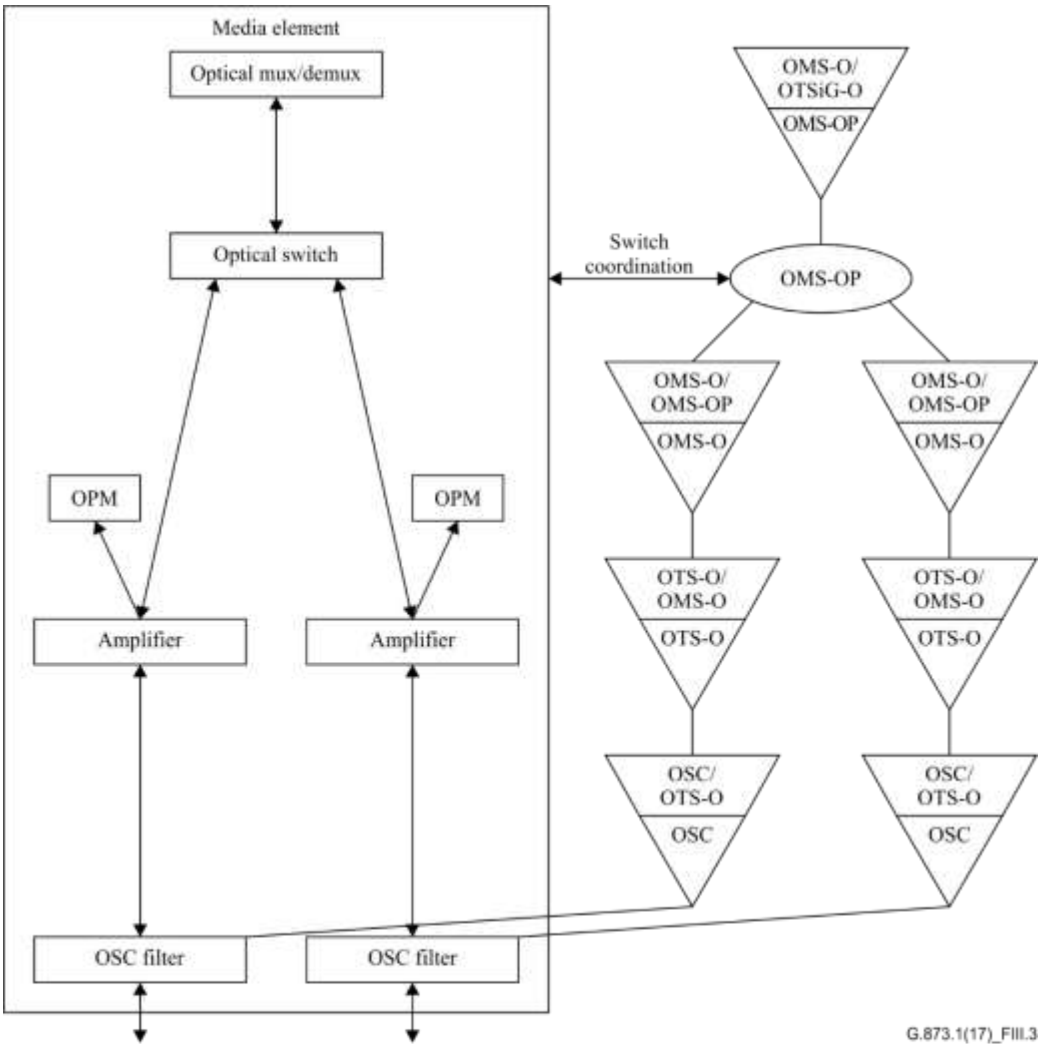


Figure III.3 – OMS OSME protection

Individual OTSi(G) protection

An optical switch (or set of such switches) can be used to protect an individual OTSi (or the set that comprise an OTSiG) prior to optical multiplexing. In this case there are separate OMS-O trails for each of the links and the OTSiG-O is protected. In the interest of maintaining continuity with the old model (which describes OCh SNC protection in substantial detail in [ITU-T G.798]), individual OTSi protection can be modelled as OCh or OTSi SNC protection, with the understanding that both an "optical connection" (i.e., appropriate media channels) and an overhead connection need to be configured and switched. This is shown in Figure III.4.

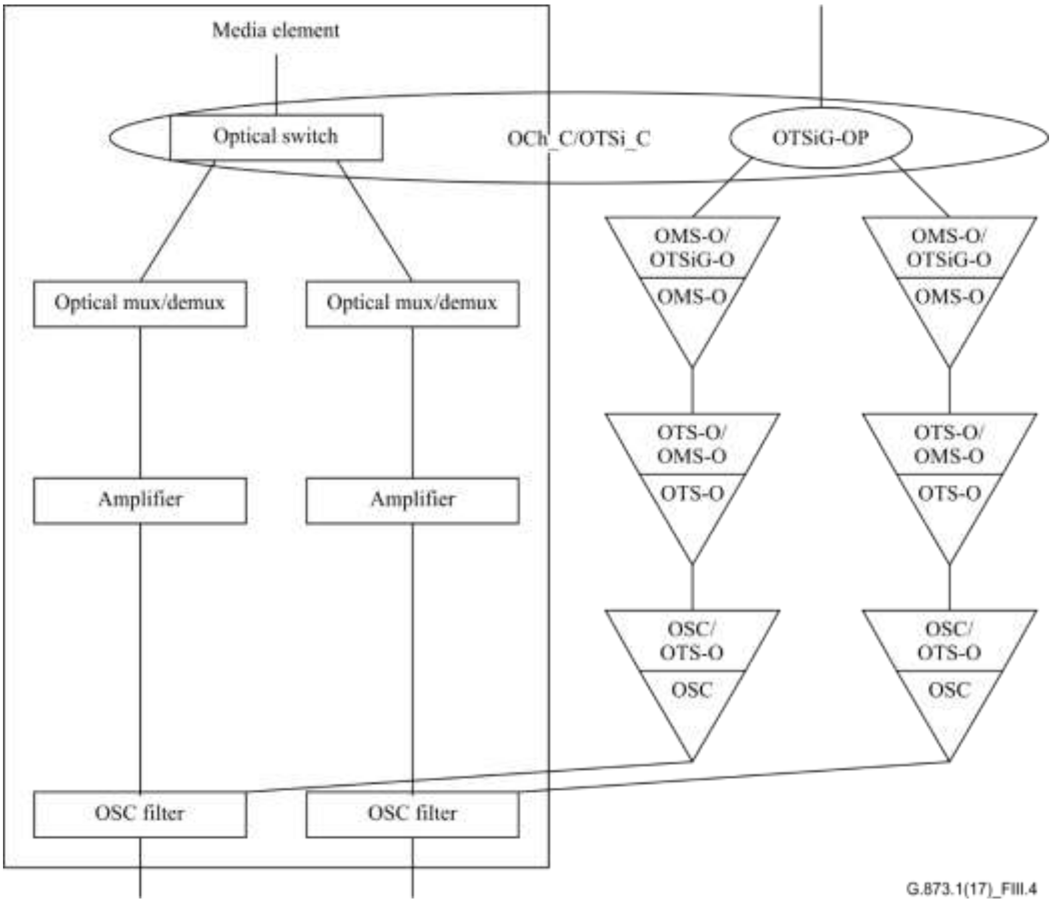


Figure III.4 – OCh or OTSi SNC protection

Media protection below the OSC filter

In this case there is no overhead part of the protection since the OSC has not yet been terminated. Figure III.5 shows media protection below the OSC filter.

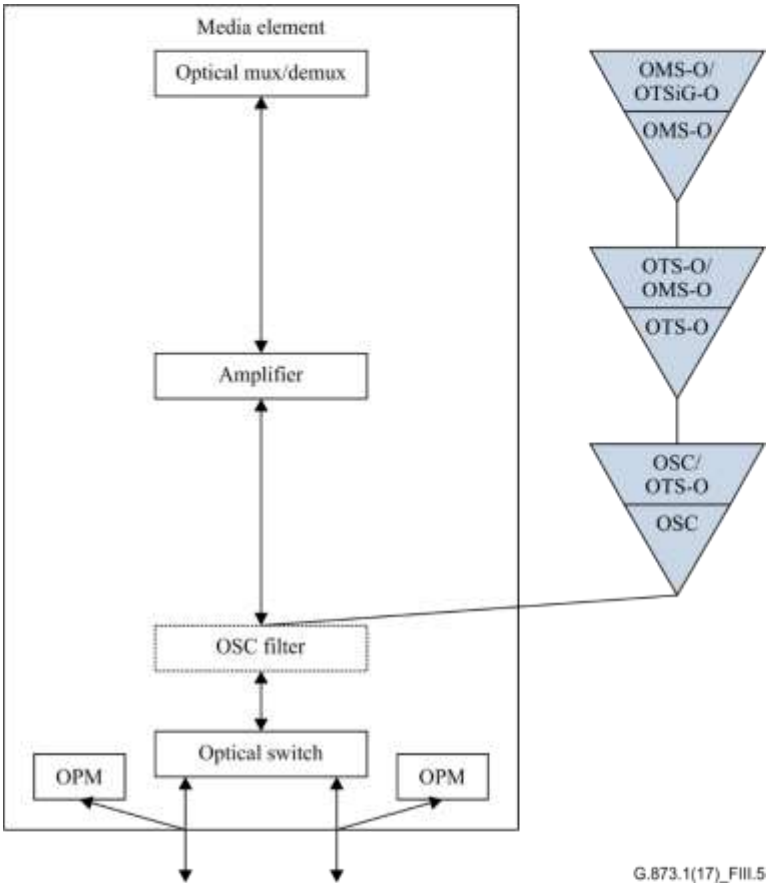


Figure III.5 – Media protection below the OSC filter

Bibliography

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

[b-ITU-T G.872] Recommendation ITU-T G.872 (2017), *Architecture of optical transport networks.*

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