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J. Ryoo, Ed.
ETRI
E. Gray, Ed.
Ericsson
H. van Helvoort
Huawei Technologies
A. D'Alessandro
Telecom Italia
T. Cheung
ETRI
E. Osborne
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MPLS Transport Profile (MPLS-TP) Linear Protection to Match the Operational Expectations of Synchronous Digital Hierarchy, Optical Transport Network, and Ethernet Transport Network Operators

Abstract

This document describes alternate mechanisms to perform some of the functions of MPLS Transport Profile (MPLS-TP) linear protection defined in RFC 6378, and also defines additional mechanisms. The purpose of these alternate and additional mechanisms is to provide operator control and experience that more closely models the behavior of linear protection seen in other transport networks.

This document also introduces capabilities and modes for linear protection. A capability is an individual behavior, and a mode is a particular combination of capabilities. Two modes are defined in this document: Protection State Coordination (PSC) mode and Automatic Protection Switching (APS) mode.

This document describes the behavior of the PSC protocol including priority logic and state machine when all the capabilities associated with the APS mode are enabled.

This document updates RFC 6378 in that the capability advertisement method defined here is an addition to that document.

Status of This Memo

This is an Internet Standards Track document.

This document is a product of the Internet Engineering Task Force (IETF). It represents the consensus of the IETF community. It has received public review and has been approved for publication by the Internet Engineering Steering Group (IESG). Further information on Internet Standards is available in Section 2 of RFC 5741.

Information about the current status of this document, any errata, and how to provide feedback on it may be obtained at http://www.rfc-editor.org/info/rfc7271.

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Table of Contents

1. Introduction

Linear protection mechanisms for the MPLS Transport Profile (MPLS-TP) are described in RFC 6378 [RFC6378] to meet the requirements described in RFC 5654 [RFC5654].

This document describes alternate mechanisms to perform some of the functions of linear protection, and also defines additional mechanisms. The purpose of these alternate and additional mechanisms is to provide operator control and experience that more closely models the behavior of linear protection seen in other transport networks, such as Synchronous Digital Hierarchy (SDH), Optical Transport Network (OTN), and Ethernet transport networks. Linear protection for SDH, OTN, and Ethernet transport networks is defined in ITU-T Recommendations G.841 [G841], G.873.1 [G873.1], and G.8031 [G8031], respectively.

The reader of this document is assumed to be familiar with [RFC6378].

The alternative mechanisms described in this document are for the following capabilities:

1. Priority modification,

2. non-revertive behavior modification,

and the following capabilities have been added to define additional mechanisms:

3. support of the Manual Switch to Working path (MS-W) command,

4. support of protection against Signal Degrade (SD), and

5. support of the Exercise (EXER) command.

The priority modification includes raising the priority of Signal Fail on Protection path (SF-P) relative to Forced Switch (FS), and raising the priority level of Clear Signal Fail (SFc) above SF-P.

Non-revertive behavior is modified to align with the behavior defined in RFC 4427 [RFC4427] as well as to follow the behavior of linear protection seen in other transport networks.

Support of the MS-W command to revert traffic to the working path in non-revertive operation is covered in this document.

Support of the protection-switching protocol against SD is covered in this document. The specifics for the method of identifying SD are out of the scope for this document and are treated similarly to Signal Fail (SF) in [RFC6378].

Support of the EXER command to test if the Protection State Coordination (PSC) communication is operating correctly is also covered in this document. Without actually switching traffic, the EXER command tests and validates the linear protection mechanism and PSC protocol including the aliveness of the priority logic, the PSC state machine, the PSC message generation and reception, and the integrity of the protection path.

This document introduces capabilities and modes. A capability is an individual behavior. The capabilities of a node are advertised using the method given in this document. A mode is a particular combination of capabilities. Two modes are defined in this document: PSC mode and Automatic Protection Switching (APS) mode.

Other modes may be defined as new combinations of the capabilities defined in this document or through the definition of additional capabilities. In either case, the specification defining a new mode will be responsible for documenting the behavior, the priority logic, and the state machine of the PSC protocol when the set of capabilities in the new mode is enabled.

This document describes the behavior, the priority logic, and the state machine of the PSC protocol when all the capabilities associated with the APS mode are enabled. The PSC protocol behavior for the PSC mode is as defined in [RFC6378].

This document updates [RFC6378] by adding a capability advertisement mechanism. It is recommended that existing implementations of the PSC protocol be updated to support this capability. Backward compatibility with existing implementations that do not support this mechanism is described in Section 9.2.1.

Implementations are expected to be configured to support a specific set of capabilities (a mode) and to reject messages that indicate the use of a different set of capabilities (a different mode). Thus, the capability advertisement is not a negotiation but a verification that peers are using the same mode.

2. Conventions Used in This Document

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC 2119 [RFC2119].

3. Acronyms

This document uses the following acronyms:

APS	Automatic Protection Switching
DNR	Do-not-Revert
EXER	Exercise
FS	Forced Switch
LO	Lockout of protection
MS	Manual Switch
MS-P	Manual Switch to Protection path
MS-W	Manual Switch to Working path
MPLS-TP	MPLS Transport Profile
NR	No Request
OC	Operator Clear
OTN	Optical Transport Network
PSC	Protection State Coordination
RR	Reverse Request
SD	Signal Degrade
SD-P	Signal Degrade on Protection path
SD-W	Signal Degrade on Working path
SDH	Synchronous Digital Hierarchy
SF	Signal Fail
SF-P	Signal Fail on Protection path
SF-W	Signal Fail on Working path
SFc	Clear Signal Fail
SFDc	Clear Signal Fail or Degrade
WTR	Wait-to-Restore

4. Capability 1: Priority Modification

[RFC6378] defines the priority of FS to be higher than that of SF-P. That document also defines the priority of Clear SF (SFc) to be low. This document defines the priority modification capability whereby the relative priorities of FS and SF-P are swapped, and the priority of Clear SF (SFc) is raised. In addition, this capability introduces the Freeze command as described in Appendix C. The rationale for these changes is detailed in the following subsections from both the technical and network operational aspects.

4.1. Motivation for Swapping Priorities of FS and SF-P

Defining the priority of FS higher than that of SF-P can result in a situation where the protected traffic is taken out of service. When the protection path fails, PSC communication may stop as a result. In this case, if any input that is supposed to be signaled to the other end has a higher priority than SF-P, then this can result in an

unpredictable protection-switching state. An example scenario that may result in an out-of-service situation is presented in Appendix A of this document.

According to Section 2.4 of [RFC5654], it MUST be possible to operate an MPLS-TP network without using a control plane. This means that the PSC communication channel is very important for the transfer of external switching commands (e.g., FS), and these commands should not rely on the presence of a control plane. In consequence, the failure of the PSC communication channel has higher priority than FS.

In other transport networks (such as SDH, OTN, and Ethernet transport networks), the priority of SF-P has been higher than that of FS. It is therefore important to offer network operators the option of having the same behavior in their MPLS-TP networks so that they can have the same operational protection-switching behavior to which they have become accustomed. Typically, an FS command is issued before network maintenance jobs (e.g., replacing optical cables or other network components). When an operator pulls out a cable on the protection path, by mistake, the traffic should continue to be protected, and the operator expects this behavior based on his/her experience with traditional transport network operations.

4.2. Motivation for Raising the Priority of SFc

The priority level of SFc defined in [RFC6378] can cause traffic disruption when a node that has experienced local signal fails on both the working and the protection paths is recovering from these failures.

A sequence diagram highlighting the problem with the priority level of SFc as defined in [RFC6378] is presented in Appendix B.

4.3. Motivation for Introducing the Freeze Command

With the priority swapping between FS and SF-P, the traffic is always moved back to the working path when SF-P occurs in Protecting Administrative state. In case network operators need an option to control their networks so that the traffic can remain on the protection path even when the PSC communication channel is broken, the Freeze command can be used. Freeze is defined to be a "local" command that is not signaled to the remote node. The use of the Freeze command is described in Appendix C.

4.4. Procedures in Support of Priority Modification

When the modified priority order specified in this document is in use, the list of local requests in order of priority SHALL be as follows (from highest to lowest):

- Clear Signal Fail
- Signal Fail on Protection path
- Forced Switch
- Signal Fail on Working path

This requires modification of the PSC Control Logic (including the state machine) relative to that described in [RFC6378]. Sections 10 and 11 present the PSC Control Logic when all capabilities of APS mode are enabled.

5. Capability 2: Non-revertive Behavior Modification

Non-revertive operation of protection switching is defined in [RFC4427]. In this operation, the traffic does not return to the working path when switch-over requests are terminated.

However, the PSC protocol defined in [RFC6378] supports this operation only when recovering from a defect condition: it does not support the non-revertive function when an operator's switch-over command, such as FS or Manual Switch (MS), is cleared. To be aligned with the behavior in other transport networks and to be consistent with [RFC4427], a node should go into the Do-not-Revert (DNR) state not only when a failure condition on the working path is cleared, but also when an operator command that requested switch-over is cleared.

This requires modification to the PSC Control Logic (including the state machine) relative to that described in [RFC6378]. Sections 10 and 11 present the PSC Control Logic when all capabilities of APS mode are enabled.

6. Capability 3: Support of the MS-W Command

6.1. Motivation for adding MS-W

Changing the non-revertive operation as described in Section 5 introduces the necessity of a new operator command to revert traffic to the working path in the DNR state. When the traffic is on the protection path in the DNR state, a Manual Switch to Working (MS-W) command is issued to switch the normal traffic back to the working

path. According to Section 4.3.3.6 (Do-not-Revert State) in [RFC6378], "To revert back to the Normal state, the administrator SHALL issue a Lockout of protection command followed by a Clear command." However, using the Lockout of protection (LO) command introduces the potential risk of an unprotected situation while the LO is in effect.

The "Manual switch-over for recovery LSP/span" command is defined in [RFC4427]. Requirement 83 in [RFC5654] states that the external commands defined in [RFC4427] MUST be supported. Since there is no support for this external command in [RFC6378], this functionality should be added to PSC. This support is provided by introducing the MS-W command. The MS-W command, as described here, corresponds to the "Manual switch-over for recovery LSP/span" command.

6.2. Terminology to Support MS-W

[RFC6378] uses the term "Manual Switch" and its acronym "MS". This document uses the term "Manual Switch to Protection path" and "MS-P" to have the same meaning, while avoiding confusion with "Manual Switch to Working path" and its acronym "MS-W".

Similarly, we modify the name of "Protecting Administrative" state (as defined in [RFC6378]) to be "Switching Administrative" state to include the case where traffic is switched to the working path as a result of the external MS-W command.

6.3. Behavior of MS-P and MS-W

MS-P and MS-W SHALL have the same priority. We consider different instances of determining the priority of the commands when they are received either in succession or simultaneously.

- When two commands are received in succession, the command that is received after the initial command SHALL be cancelled.
- If two nodes simultaneously receive commands that indicate opposite operations (i.e., one node receives MS-P and the other node receives MS-W) and transmit the indications to the remote node, the MS-W SHALL be considered to have a higher priority, and the MS-P SHALL be cancelled and discarded.

Two commands, MS-P and MS-W, are transmitted using the same Request field value but SHALL indicate in the Fault Path (FPath) value the path from which the traffic is being diverted. When traffic is switched to the protection path, the FPath field value SHALL be set to 1, indicating that traffic is being diverted from the working path. When traffic is switched to the working path, the FPath field

value SHALL be set to 0, indicating that traffic is being diverted from the protection path. The Data Path (Path) field SHALL indicate where user data traffic is being transported (i.e., if the working path is selected, then Path is set to 0; if the protection path is selected, then Path is set to 1).

When an MS command is in effect at a node, any subsequent MS or EXER command and any other lower-priority requests SHALL be ignored.

6.4. Equal-Priority Resolution for MS

[RFC6378] defines only one rule for the equal-priority condition in Section 4.3.2 as "The remote message from the far-end LER is assigned a priority just below the similar local input." In order to support the Manual Switch behavior described in Section 6.3, additional rules for equal-priority resolution are required. Since the support of protection against signal degrade also requires a similar equal-priority resolution, the rules are described in Section 7.4.

Support of this function requires changes to the PSC Control Logic (including the state machine) relative to that shown in [RFC6378]. Sections 10 and 11 present the PSC Control Logic when all capabilities of APS mode are enabled.

7. Capability 4: Support of Protection against SD

7.1. Motivation for Supporting Protection against SD

In the MPLS-TP Survivability Framework [RFC6372], both SF and SD fault conditions can be used to trigger protection switching.

[RFC6378], which defines the protection-switching protocol for MPLS-TP, does not specify how the SF and SD are detected, and specifies the protection-switching protocol associated with SF only.

The PSC protocol associated with SD is covered in this document, but the specifics for the method of identifying SD is out of scope for the protection protocol in the same way that SF detection and MS or FS command initiation are out of scope.

7.2. Terminology to Support SD

In this document, the term Clear Signal Fail or Degrade (SFDc) is used to indicate the clearance of either a degraded condition or a failure condition.

The second paragraph of Section 4.3.3.2 (Unavailable State) in [RFC6378] shows the intention of including Signal Degrade on Protection path (SD-P) in the Unavailable state. Even though the protection path can be partially available under the condition of SD-P, this document follows the same state grouping as [RFC6378] for SD-P.

The bulleted item on the Protecting Failure state in Section 3.6 of [RFC6378] includes the degraded condition in the Protecting Failure state. This document follows the same state grouping as [RFC6378] for Signal Degrade on Working path (SD-W).

7.3. Behavior of Protection against SD

To better align the behavior of MPLS-TP networks with that of other transport networks (such as SDH, OTN, and Ethernet transport networks), we define the following:

- The priorities of SD-P and SD-W SHALL be equal.
- Once a switch has been completed due to SD on one path, it will not be overridden by SD on the other path (first come, first served behavior), to avoid protection switching that cannot improve signal quality.

The SD message indicates that the transmitting node has identified degradation of the signal or integrity of the packet received on either the working path or the protection path. The FPath field SHALL identify the path that is reporting the degraded condition (i.e., if the protection path, then FPath is set to 0; if the working path, then FPath is set to 1), and the Path field SHALL indicate where the data traffic is being transported (i.e., if the working path is selected, then Path is set to 0; if the protection path is selected, then Path is set to 1).

When the SD condition is cleared and the protected domain is recovering from the situation, the Wait-to-Restore (WTR) timer SHALL be used if the protected domain is configured for revertive behavior. The WTR timer SHALL be started at the node that recovers from a local degraded condition on the working path.

Protection switching against SD is always provided by a selector bridge duplicating user data traffic and feeding it to both the working path and the protection path under SD condition. When a local or remote SD occurs on either the working path or the protection path, the node SHALL duplicate user data traffic and SHALL feed it to both the working path and the protection path. The packet duplication SHALL continue as long as any SD condition exists in the

protected domain. When the SD condition is cleared, in revertive operation, the packet duplication SHALL continue in the WTR state and SHALL stop when the node leaves the WTR state; while in non-revertive operation, the packet duplication SHALL stop immediately.

The selector bridge with the packet duplication under SD condition, which is a non-permanent bridge, is considered to be a 1:1 protection architecture.

Protection switching against SD does not introduce any modification to the operation of the selector at the sink node described in [RFC6378]. The selector chooses either the working or protection path from which to receive the normal traffic in both 1:1 and 1+1 architectures. The position of the selector, i.e., which path to receive the traffic, is determined by the PSC protocol in bidirectional switching or by the local input in unidirectional switching.

7.4. Equal-Priority Resolution

In order to support the MS behavior described in Section 6.3 and the protection against SD described in Section 7.3, it is necessary to expand rules for treating equal-priority inputs.

For equal-priority local inputs, such as MS and SD, apply a simple first-come, first-served rule. Once a local input is determined as the highest priority local input, then a subsequent equal-priority local input requesting a different action, i.e., the action results in the same PSC Request field but different FPath value, will not be presented to the PSC Control Logic as the highest local request. Furthermore, in the case of an MS command, the subsequent local MS command requesting a different action will be cancelled.

If a node is in a remote state due to a remote SD (or MS) message, a subsequent local input having the same priority but requesting a different action to the PSC Control Logic will be considered as having lower priority than the remote message and will be ignored. For example, if a node is in remote Switching Administrative state due to a remote MS-P, then any subsequent local MS-W SHALL be ignored and automatically cancelled. If a node is in remote Unavailable state due to a remote SD-P, then any subsequent local SD-W input will be ignored. However, the local SD-W SHALL continue to appear in the Local Request Logic as long as the SD condition exists, but it SHALL NOT be the top-priority global request, which determines the state transition at the PSC Control Logic.

Cases where two end-points of the protected domain simultaneously receive local triggers of the same priority that request different actions may occur (for example, one node receives SD-P and the other receives SD-W). Subsequently, each node will receive a remote message with the opposing action indication. To address these cases, we define the following priority resolution rules:

- When MS-W and MS-P occur simultaneously at both nodes, MS-W SHALL be considered as having higher priority than MS-P at both nodes.

- When SD-W and SD-P occur simultaneously at both nodes, the SD on the standby path (the path from which the selector does not select the user data traffic) is considered as having higher priority than the SD on the active path (the path from which the selector selects the user data traffic) regardless of its origin (local or remote message). Therefore, no unnecessary protection switching is performed, and the user data traffic continues to be selected from the active path.

In the preceding paragraphs, "simultaneously" refers to the case a sent SD (or MS) request has not been confirmed by the remote end in bidirectional protection switching. When a local node that has transmitted an SD message receives an SD (or MS) message that indicates a different value of Path field from the value of Path field in the transmitted SD (or MS) message, both the local and remote SD requests are considered to occur simultaneously.

The addition of support for protection against SD requires modification to the PSC Control Logic (including the state machine) relative to that described in [RFC6378]. Sections 10 and 11 present the PSC Control Logic when all capabilities of APS mode are enabled.

8. Capability 5: Support of EXER Command

The EXER command is used to verify the correct operation of the PSC communication, such as the aliveness of the Local Request Logic, the integrity of the PSC Control Logic, the PSC message generation and reception mechanism, and the integrity of the protection path. EXER does not trigger any actual traffic switching.

The command is only relevant for bidirectional protection switching, since it is dependent upon receiving a response from the remote node. The EXER command is assigned lower priority than any switching message. It may be used regardless of the traffic usage of the working path.

When a node receives a remote EXER message, it SHOULD respond with a Reverse Request (RR) message with the FPath and Path fields set according to the current condition of the node. The RR message SHALL be generated only in response to a remote EXER message.

This command is documented in R84 of [RFC5654].

If EXER commands are input at both ends, then a race condition may arise. This is resolved as follows:

- If a node has issued EXER and receives EXER before receiving RR, it MUST treat the received EXER as it would an RR, and it SHOULD NOT respond with RR.

The following PSC Requests are added to the PSC Request field to support the Exercise command (see also Section 14.1):

(3) Exercise - indicates that the transmitting end-point is exercising the protection channel and mechanism. FPath and Path are set to the same value of the No Request (NR), RR, or DNR message whose transmission is stopped by EXER.

(2) Reverse Request - indicates that the transmitting end-point is responding to an EXER command from the remote node. FPath and Path are set to the same value of the NR or DNR message whose transmission is stopped by RR.

The relative priorities of EXER and RR are defined in Section 10.2.

9. Capabilities and Modes

9.1. Capabilities

A Capability is an individual behavior whose use is signaled in a Capabilities TLV, which is placed in Optional TLVs field inside the PSC message shown in Figure 2 of [RFC6378]. The format of the Capabilities TLV is:

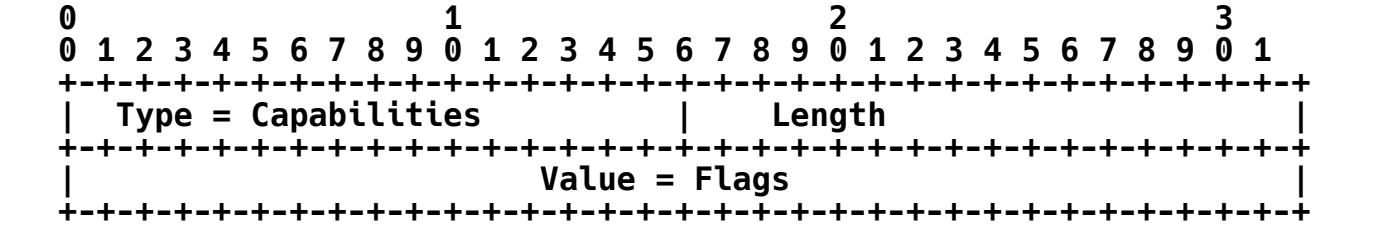

Figure 1: Format of Capabilities TLV

The value of the Type field is 1.

The value of the Length field is the length of the Flags field in octets. The length of the Flags field MUST be a multiple of 4 octets and MUST be the minimum required to signal all the required capabilities.

Section 4 to Section 8 discuss five capabilities that are signaled using the five most significant bits; if a node wishes to signal these five capabilities, it MUST send a Flags field of 4 octets. A node would send a Flags field greater than 4 octets only if it had more than 32 Capabilities to indicate. All unused bits MUST be set to zero.

If the bit assigned for an individual capability is set to 1, it indicates the sending node's intent to use that capability in the protected domain. If a bit is set to 0, the sending node does not intend to use the indicated capability in the protected domain. Note that it is not possible to distinguish between the intent not to use a capability and a node's complete non-support (i.e., lack of implementation) of a given capability.

This document defines five specific capabilities that are described in Section 4 to Section 8. Each capability is assigned bit as follows:

0x80000000: priority modification

0x40000000: non-revertive behavior modification

0x20000000: support of MS-W command

0x10000000: support of protection against SD

0x08000000: support of EXER command

If all the five capabilities should be used, a node SHALL set the Flags field to 0xF8000000.

9.1.1. Sending and Receiving the Capabilities TLV

A node MUST include its Capabilities TLV in every PSC message that it transmits. The transmission and acceptance of the PSC message is described in Section 4.1 of [RFC6378].

When a node receives a Capabilities TLV, it MUST compare the Flags value to its most recent Flags value transmitted by the node. If the two are equal, the protected domain is said to be running in the mode

indicated by that set of capabilities (see Section 9.2). If the sent and received Capabilities TLVs are not equal, this indicates a Capabilities TLV mismatch. When this happens, the node MUST alert the operator and MUST NOT perform any protection switching until the operator resolves the mismatch between the two end-points.

9.2. Modes

A mode is a given set of Capabilities. Modes are shorthand; referring to a set of capabilities by their individual values or by the name of their mode does not change the protocol behavior. This document defines two modes -- PSC and APS. Capabilities TLVs with other combinations than the one specified by a mode are not supported in this specification.

9.2.1. PSC Mode

PSC mode is defined as the lack of support for any of the additional capabilities defined in this document -- that is, a Capabilities set of 0x0. It is the behavior specified in [RFC6378].

There are two ways to declare PSC mode. A node can send no Capabilities TLV at all since there are no TLV units defined in [RFC6378], or it can send a Capabilities TLV with Flags value set to 0x0. In order to allow backward compatibility between two end-points -- one which supports sending the Capabilities TLV, and one which does not, the node that has the ability to send and process the PSC mode Capabilities TLV MUST be able to both send the PSC mode Capabilities TLV and send no Capabilities TLV at all. An implementation MUST be configurable between these two options.

9.2.2. APS Mode

APS mode is defined as the use of all the five specific capabilities, which are described in Sections 4 to 8 in this document. APS mode is indicated with the Flags value of 0xF8000000.

10. PSC Protocol in APS Mode

This section and the following section define the behavior of the PSC protocol when all of the aforementioned capabilities are enabled, i.e., APS mode.

10.1. Request Field in PSC Protocol Message

This document defines two new values for the "Request" field in the PSC protocol message that is shown in Figure 2 of [RFC6378] as follows:

(2) Reverse Request

(3) Exercise

See also Section 14.1 of this document.

10.2. Priorities of Local Inputs and Remote Requests

Based on the description in Sections 3 and 4.3.2 in [RFC6378], the priorities of multiple outstanding local inputs are evaluated in the Local Request Logic, where the highest priority local input (highest local request) is determined. This highest local request is passed to the PSC Control Logic that will determine the higher-priority input (top-priority global request) between the highest local request and the last received remote message. When a remote message comes to the PSC Control Logic, the top-priority global request is determined between this remote message and the highest local request that is present. The top-priority global request is used to determine the state transition, which is described in Section 11. In this document, in order to simplify the description on the PSC Control Logic, we strictly decouple the priority evaluation from the state transition table lookup.

The priorities for both local and remote requests are defined as follows from highest to lowest:

- Operator Clear (Local only)
- Lockout of protection (Local and Remote)
- Clear Signal Fail or Degrade (Local only)
- Signal Fail on Protection path (Local and Remote)
- Forced Switch (Local and Remote)

- Signal Fail on Working path (Local and Remote)
- Signal Degrade on either Protection path or Working path (Local and Remote)
- Manual Switch to either Protection path or Working path (Local and Remote)
- WTR Timer Expiry (Local only)
- WTR (Remote only)
- Exercise (Local and Remote)
- Reverse Request (Remote only)
- Do-Not-Revert (Remote only)
- No Request (Remote and Local)

Note that the "Local only" requests are not transmitted to the remote node. Likewise, the "Remote only" requests do not exist in the Local Request Logic as local inputs. For example, the priority of WTR only applies to the received WTR message, which is generated from the remote node. The remote node that is running the WTR timer in the WTR state has no local request.

The remote SF and SD on either the working path or the protection path and the remote MS to either the working path or the protection path are indicated by the values of the Request and FPath fields in the PSC message.

The remote request from the remote node is assigned a priority just below the same local request except for NR and equal-priority requests, such as SD and MS. Since a received NR message needs to be used in the state transition table lookup when there is no outstanding local request, the remote NR request SHALL have a higher priority than the local NR. For the equal-priority requests, see Section 10.2.1.

10.2.1. Equal-Priority Requests

As stated in Section 10.2, the remote request from the remote node is assigned a priority just below the same local request. However, for equal-priority requests, such as SD and MS, the priority SHALL be evaluated as described in this section.

For equal-priority local requests, the first-come, first-served rule SHALL be applied. Once a local request appears in the Local Request Logic, a subsequent equal-priority local request requesting a different action, i.e., the action results in the same Request value but a different FPath value, SHALL be considered to have a lower priority. Furthermore, in the case of an MS command, the subsequent local MS command requesting a different action SHALL be rejected and cleared.

When the priority is evaluated in the PSC Control Logic between the highest local request and a remote request, the following equal-priority resolution rules SHALL be applied:

- If two requests request the same action, i.e., the same Request and FPath values, then the local request SHALL be considered to have a higher priority than the remote request.

- When the highest local request comes to the PSC Control Logic, if the remote request that requests a different action exists, then the highest local request SHALL be ignored and the remote request SHALL remain to be the top-priority global request. In the case of an MS command, the local MS command requesting a different action SHALL be cancelled.

- When the remote request comes to the PSC Control Logic, if the highest local request that requests a different action exists, then the top-priority global request SHALL be determined by the following rules:

  * For MS requests, the MS-W request SHALL be considered to have a higher priority than the MS-P request. The node that has the local MS-W request SHALL maintain the local MS-W request as the top-priority global request. The other node that has the local MS-P request SHALL cancel the MS-P command and SHALL generate "Operator Clear" internally as the top-priority global request.

  * For SD requests, the SD on the standby path (the path from which the selector does not select the user data traffic) SHALL be considered to have a higher priority than the SD on the active path (the path from which the selector selects the user data traffic) regardless of its origin (local or remote message). The node that has the SD on the standby path SHALL maintain the local SD on the standby path request as the top-priority global request. The other node that has local SD on the active path SHALL use the remote SD on the standby path as the top-priority global request to lookup the state transition

table. The differentiation of the active and standby paths is based upon which path had been selected for the user data traffic when each node detected its local SD.

10.3. Acceptance and Retention of Local Inputs

A local input indicating a defect, such as SF-P, SF-W, SD-P, and SD-W, SHALL be accepted and retained persistently in the Local Request Logic as long as the defect condition exists. If there is any higher-priority local input than the local defect input, the higher-priority local input is passed to the PSC Control Logic as the highest local request, but the local defect input cannot be removed but remains in the Local Request Logic. When the higher-priority local input is cleared, the local defect will become the highest local request if the defect condition still exists.

The Operator Clear (OC) command, SFDc, and WTR Timer Expiry are not persistent. Once they appear to the Local Request Logic and complete all the operations in the protection-switching control, they SHALL disappear.

The LO, FS, MS, and EXER commands SHALL be rejected if there is any higher-priority local input in the Local Request Logic. If a new higher-priority local request (including an operator command) is accepted, any previous lower-priority local operator command SHALL be cancelled. When any higher-priority remote request is received, a lower-priority local operator command SHALL be cancelled. The cancelled operator command is cleared. If the operators wish to renew the cancelled command, then they should reissue the command.

11. State Transition Tables in APS Mode

When there is a change in the highest local request or in remote PSC messages, the top-priority global request SHALL be evaluated, and the state transition tables SHALL be looked up in the PSC Control Logic. The following rules are applied to the operation related to the state transition table lookup.

- If the top-priority global request, which determines the state transition, is the highest local request, the local state transition table in Section 11.1 SHALL be used to decide the next state of the node. Otherwise, the remote state transition table in Section 11.2 SHALL be used.

- If in remote state, the highest local defect condition (SF-P, SF-W, SD-P, or SD-W) SHALL always be reflected in the Request and FPath fields.

- For the node currently in the local state, if the top-priority global request is changed to OC or SFDc, causing the next state to be Normal, WTR, or DNR, then all the local and remote requests SHALL be re-evaluated as if the node is in the state specified in the footnotes to the state transition tables, before deciding the final state. If there are no active requests, the node enters the state specified in the footnotes to the state transition tables. This re-evaluation is an internal operation confined within the local node, and the PSC messages are generated according to the final state.

- The WTR timer is started only when the node that has recovered from a local failure or degradation enters the WTR state. A node that is entering into the WTR state due to a remote WTR message does not start the WTR timer. The WTR timer SHALL be stopped when any local or remote request triggers the state change out of the WTR state.

The extended states, as they appear in the table, are as follows:

N	Normal state
UA:LO:L	Unavailable state due to local LO command
UA:P:L	Unavailable state due to local SF-P
UA:DP:L	Unavailable state due to local SD-P
UA:LO:R	Unavailable state due to remote LO message
UA:P:R	Unavailable state due to remote SF-P message
UA:DP:R	Unavailable state due to remote SD-P message
PF:W:L	Protecting Failure state due to local SF-W
PF:DW:L	Protecting Failure state due to local SD-W
PF:W:R	Protecting Failure state due to remote SF-W message
PF:DW:R	Protecting Failure state due to remote SD-W message
SA:F:L	Switching Administrative state due to local FS command
SA:MW:L	Switching Administrative state due to local MS-W command
SA:MP:L	Switching Administrative state due to local MS-P command
SA:F:R	Switching Administrative state due to remote FS message
SA:MW:R	Switching Administrative state due to remote MS-W message
SA:MP:R	Switching Administrative state due to remote MS-P message
WTR	Wait-to-Restore state
DNR	Do-not-Revert state
E::L	Exercise state due to local EXER command
E::R	Exercise state due to remote EXER message

Each state corresponds to the transmission of a particular set of Request, FPath, and Path fields. The table below lists the message that is generally sent in each particular state. If the message to be sent in a particular state deviates from the table below, it is noted in the footnotes of the state transition tables.

State	Request(FPath,Path)
N	NR(0,0)
UA:LO:L	LO(0,0)
UA:P:L	SF(0,0)
UA:DP:L	SD(0,0)
UA:LO:R	highest local request(local FPath,0)
UA:P:R	highest local request(local FPath,0)
UA:DP:R	highest local request(local FPath,0)
PF:W:L	SF(1,1)
PF:DW:L	SD(1,1)
PF:W:R	highest local request(local FPath,1)
PF:DW:R	highest local request(local FPath,1)
SA:F:L	FS(1,1)
SA:MW:L	MS(0,0)
SA:MP:L	MS(1,1)
SA:F:R	highest local request(local FPath,1)
SA:MW:R	NR(0,0)
SA:MP:R	NR(0,1)
WTR	WTR(0,1)
DNR	DNR(0,1)
E::L	EXER(0,x), where x is the existing Path value when Exercise command is issued.
E::R	RR(0,x), where x is the existing Path value when RR message is generated.

Some operation examples of APS mode are shown in Appendix D.

In the state transition tables below, the letter 'i' stands for "ignore" and is an indication to remain in the current state and continue transmitting the current PSC message

11.1. State Transition by Local Inputs

	OC	LO	SFDc	SF-P	FS	SF-W
N	i	UA:LO:L	i	UA:P:L	SA:F:L	PF:W:L
UA:LO:L	(1)	i	i	i	i	i
UA:P:L	i	UA:LO:L	(1)	i	i	i
UA:DP:L	i	UA:LO:L	(1)	UA:P:L	SA:F:L	PF:W:L
UA:LO:R	i	UA:LO:L	i	UA:P:L	i	PF:W:L
UA:P:R	i	UA:LO:L	i	UA:P:L	i	PF:W:L
UA:DP:R	i	UA:LO:L	i	UA:P:L	SA:F:L	PF:W:L
PF:W:L	i	UA:LO:L	(2)	UA:P:L	SA:F:L	i
PF:DW:L	i	UA:LO:L	(2)	UA:P:L	SA:F:L	PF:W:L
PF:W:R	i	UA:LO:L	i	UA:P:L	SA:F:L	PF:W:L
PF:DW:R	i	UA:LO:L	i	UA:P:L	SA:F:L	PF:W:L
SA:F:L	(3)	UA:LO:L	i	UA:P:L	i	i
SA:MW:L	(1)	UA:LO:L	i	UA:P:L	SA:F:L	PF:W:L
SA:MP:L	(3)	UA:LO:L	i	UA:P:L	SA:F:L	PF:W:L
SA:F:R	i	UA:LO:L	i	UA:P:L	SA:F:L	PF:W:L
SA:MW:R	i	UA:LO:L	i	UA:P:L	SA:F:L	PF:W:L
SA:MP:R	i	UA:LO:L	i	UA:P:L	SA:F:L	PF:W:L
WTR	(4)	UA:LO:L	i	UA:P:L	SA:F:L	PF:W:L
DNR	i	UA:LO:L	i	UA:P:L	SA:F:L	PF:W:L
E::L	(5)	UA:LO:L	i	UA:P:L	SA:F:L	PF:W:L
E::R	i	UA:LO:L	i	UA:P:L	SA:F:L	PF:W:L

(Continued)

	SD-P	SD-W	MS-W	MS-P	WTRExp	EXER
N	UA:DP:L	PF:DW:L	SA:MW:L	SA:MP:L	i	E::L
UA:LO:L	i	i	i	i	i	i
UA:P:L	i	i	i	i	i	i
UA:DP:L	i	i	i	i	i	i
UA:LO:R	UA:DP:L	PF:DW:L	i	i	i	i
UA:P:R	UA:DP:L	PF:DW:L	i	i	i	i
UA:DP:R	UA:DP:L	PF:DW:L	i	i	i	i
PF:W:L	i	i	i	i	i	i
PF:DW:L	i	i	i	i	i	i
PF:W:R	UA:DP:L	PF:DW:L	i	i	i	i
PF:DW:R	UA:DP:L	PF:DW:L	i	i	i	i
SA:F:L	i	i	i	i	i	i
SA:MW:L	UA:DP:L	PF:DW:L	i	i	i	i
SA:MP:L	UA:DP:L	PF:DW:L	i	i	i	i
SA:F:R	UA:DP:L	PF:DW:L	i	i	i	i
SA:MW:R	UA:DP:L	PF:DW:L	SA:MW:L	i	i	i
SA:MP:R	UA:DP:L	PF:DW:L	i	SA:MP:L	i	i
WTR	UA:DP:L	PF:DW:L	SA:MW:L	SA:MP:L	(6)	i
DNR	UA:DP:L	PF:DW:L	SA:MW:L	SA:MP:L	i	E::L
E::L	UA:DP:L	PF:DW:L	SA:MW:L	SA:MP:L	i	i
E::R	UA:DP:L	PF:DW:L	SA:MW:L	SA:MP:L	i	E::L

NOTES:

(1) Re-evaluate to determine the final state as if the node is in the Normal state. If there are no active requests, the node enters the Normal State.

(2) In the case that both local input after SFDc and the last received remote message are NR, the node enters into the WTR state when the domain is configured for revertive behavior, or the node enters into the DNR state when the domain is configured for non-revertive behavior. In all the other cases, where one or more active requests exist, re-evaluate to determine the final state as if the node is in the Normal state.

(3) Re-evaluate to determine final state as if the node is in the Normal state when the domain is configured for revertive behavior, or as if the node is in the DNR state when the domain is configured for non-revertive behavior. If there are no active requests, the node enters either the Normal state when the domain is configured for revertive behavior or the DNR state when the domain is configured for non-revertive behavior.

(4) Remain in the WTR state and send an NR(0,1) message. Stop the WTR timer if it is running. In APS mode, OC can cancel the WTR timer and hasten the state transition to the Normal state as in other transport networks.

(5) If Path value is 0, re-evaluate to determine final state as if the node is in the Normal state. If Path value is 1, re-evaluate to determine final state as if the node is in the DNR state. If there are no active requests, the node enters the Normal state when Path value is 0, or the DNR state when Path value is 1.

(6) Remain in the WTR state and send an NR(0,1) message.

11.2. State Transition by Remote Messages

	LO	SF-P	FS	SF-W	SD-P	SD-W
N	UA:LO:R	UA:P:R	SA:F:R	PF:W:R	UA:DP:R	PF:DW:R
UA:LO:L	i	i	i	i	i	i
UA:P:L	UA:LO:R	i	i	i	i	i
UA:DP:L	UA:LO:R	UA:P:R	SA:F:R	PF:W:R	i	(7)
UA:LO:R	i	UA:P:R	SA:F:R	PF:W:R	UA:DP:R	PF:DW:R
UA:P:R	UA:LO:R	i	SA:F:R	PF:W:R	UA:DP:R	PF:DW:R
UA:DP:R	UA:LO:R	UA:P:R	SA:F:R	PF:W:R	i	PF:DW:R
PF:W:L	UA:LO:R	UA:P:R	SA:F:R	i	i	i
PF:DW:L	UA:LO:R	UA:P:R	SA:F:R	PF:W:R	(8)	i
PF:W:R	UA:LO:R	UA:P:R	SA:F:R	i	UA:DP:R	PF:DW:R
PF:DW:R	UA:LO:R	UA:P:R	SA:F:R	PF:W:R	UA:DP:R	i
SA:F:L	UA:LO:R	UA:P:R	i	i	i	i
SA:MW:L	UA:LO:R	UA:P:R	SA:F:R	PF:W:R	UA:DP:R	PF:DW:R
SA:MP:L	UA:LO:R	UA:P:R	SA:F:R	PF:W:R	UA:DP:R	PF:DW:R
SA:F:R	UA:LO:R	UA:P:R	i	PF:W:R	UA:DP:R	PF:DW:R
SA:MW:R	UA:LO:R	UA:P:R	SA:F:R	PF:W:R	UA:DP:R	PF:DW:R
SA:MP:R	UA:LO:R	UA:P:R	SA:F:R	PF:W:R	UA:DP:R	PF:DW:R
WTR	UA:LO:R	UA:P:R	SA:F:R	PF:W:R	UA:DP:R	PF:DW:R
DNR	UA:LO:R	UA:P:R	SA:F:R	PF:W:R	UA:DP:R	PF:DW:R
E::L	UA:LO:R	UA:P:R	SA:F:R	PF:W:R	UA:DP:R	PF:DW:R
E::R	UA:LO:R	UA:P:R	SA:F:R	PF:W:R	UA:DP:R	PF:DW:R

(Continued)

	MS-W	MS-P	WTR	EXER	RR	DNR	NR
N	SA:MW:R	SA:MP:R	i	E::R	i	i	i
UA:LO:L	i	i	i	i	i	i	i
UA:P:L	i	i	i	i	i	i	i
UA:DP:L	i	i	i	i	i	i	i
UA:LO:R	SA:MW:R	SA:MP:R	i	E::R	i	i	N
UA:P:R	SA:MW:R	SA:MP:R	i	E::R	i	i	N
UA:DP:R	SA:MW:R	SA:MP:R	i	E::R	i	i	N
PF:W:L	i	i	i	i	i	i	i
PF:DW:L	i	i	i	i	i	i	i
PF:W:R	SA:MW:R	SA:MP:R	(9)	E::R	i	(10)	(11)
PF:DW:R	SA:MW:R	SA:MP:R	(9)	E::R	i	(10)	(11)
SA:F:L	i	i	i	i	i	i	i
SA:MW:L	i	i	i	i	i	i	i
SA:MP:L	i	i	i	i	i	i	i
SA:F:R	SA:MW:R	SA:MP:R	i	E::R	i	DNR	N
SA:MW:R	i	SA:MP:R	i	E::R	i	i	N
SA:MP:R	SA:MW:R	i	i	E::R	i	DNR	N
WTR	SA:MW:R	SA:MP:R	i	i	i	i	(12)
DNR	SA:MW:R	SA:MP:R	(13)	E::R	i	i	i
E::L	SA:MW:R	SA:MP:R	i	i	i	i	i
E::R	SA:MW:R	SA:MP:R	i	i	i	DNR	N

NOTES:

(7) If the received SD-W message has Path=0, ignore the message. If the received SD-W message has Path=1, go to the PF:DW:R state and transmit an SD(0,1) message.

(8) If the received SD-P message has Path=1, ignore the message. If the received SD-P message has Path=0, go to the UA:DP:R state and transmit an SD(1,0) message.

(9) Transition to the WTR state and continue to send the current message.

(10) Transition to the DNR state and continue to send the current message.

(11) If the received NR message has Path=1, transition to the WTR state if the domain is configured for revertive behavior, else transition to the DNR state. If the received NR message has Path=0, transition to the Normal state.

(12) If the receiving node's WTR timer is running, maintain the current state and message. If the WTR timer is not running, transition to the Normal state.

(13) Transit to the WTR state and send an NR(0,1) message. The WTR timer is not initiated.

11.3. State Transition for 1+1 Unidirectional Protection

The state transition tables given in Sections 11.1 and 11.2 are for bidirectional protection switching, where remote PSC protocol messages are used to determine the protection-switching actions. 1+1 unidirectional protection switching does not require the remote information in the PSC protocol message and acts upon local inputs only. The state transition by local inputs in Section 11.1 SHALL be reused for 1+1 unidirectional protection under the following conditions:

- The value of Request field in the received remote message is ignored and always assumed to be no request.
- Replace footnote (4) with "Stop the WTR timer and transit to the Normal state."
- Replace footnote (6) with "Transit to the Normal state."
- Exercise command is not relevant.

12. Provisioning Mismatch and Protocol Failure in APS Mode

The remote PSC message that is received from the remote node is subject to the detection of provisioning mismatch and protocol failure conditions. In APS mode, provisioning mismatches are handled as follows:

- If the PSC message is received from the working path due to working/protection path configuration mismatch, the node MUST alert the operator and MUST NOT perform any protection switching until the operator resolves this path configuration mismatch.
- In the case that the mismatch happens in the two-bit "Protection Type (PT)" field, which indicates permanent/selector bridge type and uni/bidirectional switching type:

  * If the value of the PT field of one side is 2 (i.e., selector bridge) and that of the other side is 1 or 3 (i.e., permanent bridge), then this event MUST be notified to the operator and each node MUST NOT perform any protection switching until the operator resolves this bridge type mismatch.

  * If the bridge type matches but the switching type mismatches, i.e., one side has PT=1 (unidirectional switching) while the other side has PT=2 or 3 (bidirectional switching), then the node provisioned for bidirectional switching SHOULD fall back to unidirectional switching to allow interworking. The node SHOULD notify the operator of this event.

- If the "Revertive (R)" bit mismatches, two sides will interwork and traffic is protected according to the state transition definition given in Section 11. The node SHOULD notify the operator of this event.

- If the Capabilities TLV mismatches, the node MUST alert the operator and MUST NOT perform any protection switching until the operator resolves the mismatch in the Capabilities TLV.

The following are the protocol failure situations and the actions to be taken:

- No match in sent "Data Path (Path)" and received "Data Path (Path)" for more than 50 ms: The node MAY continue to perform protection switching and SHOULD notify the operator of this event.

- No PSC message is received on the protection path during at least 3.5 times the long PSC message interval (e.g., at least 17.5 seconds with a default message interval of 5 seconds), and there is no defect on the protection path: The node MUST alert the operator and MUST NOT perform any protection switching until the operator resolves this defect.

13. Security Considerations

This document introduces no new security risks. [RFC6378] points out that MPLS relies on assumptions about the difficulty of traffic injection and assumes that the control plane does not have end-to-end security. [RFC5920] describes MPLS security issues and generic methods for securing traffic privacy and integrity. MPLS use should conform to such advice.

14. IANA Considerations

14.1. MPLS PSC Request Registry

In the "Generic Associated Channel (G-ACh) Parameters" registry, IANA maintains the "MPLS PSC Request Registry".

IANA has assigned the following two new code points from this registry.

Value	Description	Reference
2	Reverse Request	(this document)
3	Exercise	(this document)

14.2. MPLS PSC TLV Registry

In the "Generic Associated Channel (G-ACh) Parameters" registry, IANA maintains the "MPLS PSC TLV Registry".

This document defines the following new value for the Capabilities TLV type in the "MPLS PSC TLV Registry".

Value	Description	Reference
1	Capabilities	(this document)

14.3. MPLS PSC Capability Flag Registry

IANA has created and now maintains a new registry within the "Generic Associated Channel (G-ACh) Parameters" registry called "MPLS PSC Capability Flag Registry". All flags within this registry SHALL be allocated according to the "Standards Action" procedures as specified in RFC 5226 [RFC5226].

The length of each flag MUST be a multiple of 4 octets. This document defines 4-octet flags. Flags greater than 4 octets SHALL be used only if more than 32 Capabilities need to be defined. The flags defined in this document are:

Bit	Hex Value	Capability	Reference
0	0x80000000	priority modification	(this document)
1	0x40000000	non-revertive behavior modification	(this document)
2	0x20000000	support of MS-W command	(this document)
3	0x10000000	support of protection against SD	(this document)
4	0x08000000	support of EXER command	(this document)
5-31		Unassigned	(this document)

15. Acknowledgements

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16.1. Normative References

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16.2. Informative References

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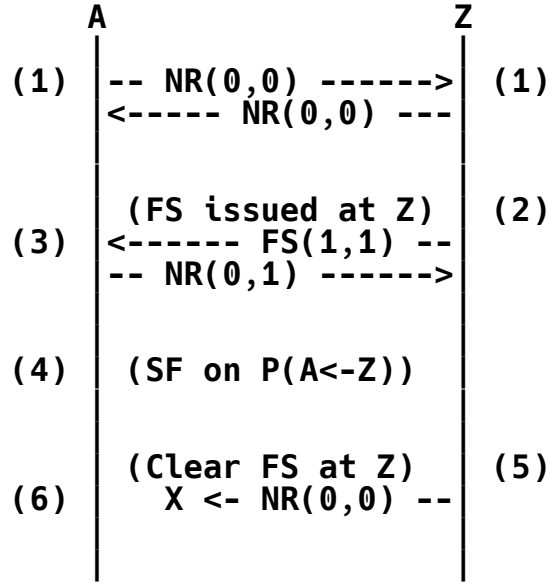
[RFC5920] Fang, L., "Security Framework for MPLS and GMPLS Networks", RFC 5920, July 2010.

[RFC6372] Sprecher, N. and A. Farrel, "MPLS Transport Profile (MPLS-TP) Survivability Framework", RFC 6372, September 2011.

Appendix A. An Example of an Out-of-Service Scenario

The sequence diagram shown is an example of the out-of-service scenarios based on the priority level defined in [RFC6378]. The first PSC message that differs from the previous PSC message is shown.



(1) Each end is in the Normal state and transmits NR(0,0) messages.

(2) When a FS command is issued at node Z, node Z goes into local Protecting Administrative state (PA:F:L) and begins transmission of an FS(1,1) message.

(3) A remote FS message causes node A to go into remote Protecting Administrative state (PA:F:R), and node A begins transmitting NR(0,1) messages.

(4) When node A detects a unidirectional SF-P, node A keeps sending an NR(0,1) message because SF-P is ignored under the PA:F:R state.

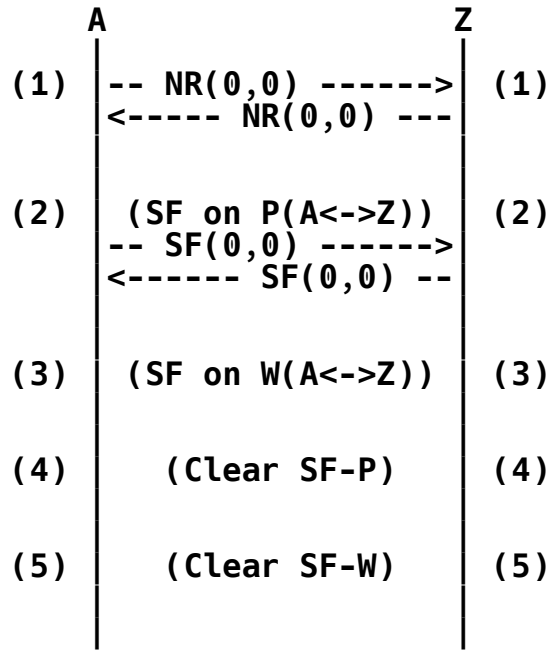
(5) When a Clear command is issued at node Z, node Z goes into the Normal state and begins transmission of NR(0,0) messages.

(6) But, node A cannot receive PSC message because of local unidirectional SF-P. Because no valid PSC message is received over a period of several successive message intervals, the last valid received message remains applicable, and the node A continue to transmit an NR(0,1) message in the PA:F:R state.

Now, there exists a mismatch between the selector and bridge positions of node A (transmitting an NR(0,1) message) and node Z (transmitting an NR(0,0) message). It results in an out-of-service situation even when there is neither SF-W nor FS.

Appendix B. An Example of a Sequence Diagram Showing the Problem with the Priority Level of SFc

An example of a sequence diagram showing the problem with the priority level of SFc defined in [RFC6378] is given below. The following sequence diagram depicts the case when the bidirectional signal fails. However, other cases with unidirectional signal fails can result in the same problem. The first PSC message that differs from the previous PSC message is shown.



(1) Each end is in the Normal state and transmits NR(0,0) messages.

(2) When SF-P occurs, each node enters into the UA:P:L state and transmits SF(0,0) messages. Traffic remains on the working path.

(3) When SF-W occurs, each node remains in the UA:P:L state as SF-W has a lower priority than SF-P. Traffic is still on the working path. Traffic cannot be delivered, as both the working path and the protection path are experiencing signal fails.

(4) When SF-P is cleared, the local "Clear SF-P" request cannot be presented to the PSC Control Logic, which takes the highest local request and runs the PSC state machine, since the priority of "Clear SF-P" is lower than that of SF-W. Consequently, there is no change in state, and the selector and/or bridge keep pointing at the working path, which has SF condition.

Now, traffic cannot be delivered while the protection path is recovered and available. It should be noted that the same problem will occur in the case that the sequence of SF-P and SF-W events is changed.

If we further continue with this sequence to see what will happen after SF-W is cleared:

(5) When SF-W is cleared, the local "Clear SF-W" request can be passed to the PSC Control Logic, as there is no higher-priority local input, but it will be ignored in the PSC Control Logic according to the state transition definition in [RFC6378]. There will be no change in state or protocol message transmitted.

As SF-W is now cleared and the selector and/or bridge are still pointing at the working path, traffic delivery is resumed. However, each node is in the UA:P:L state and transmitting SF(0,0) messages, while there exists no outstanding request for protection switching. Moreover, any future legitimate protection-switching requests, such as SF-W, will be rejected as each node thinks the protection path is unavailable.

Appendix C. Freeze Command

The "Freeze" command applies only to the local node of the protection group and is not signaled to the remote node. This command freezes the state of the protection group. Until the Freeze is cleared, additional local commands are rejected, and condition changes and received PSC information are ignored.

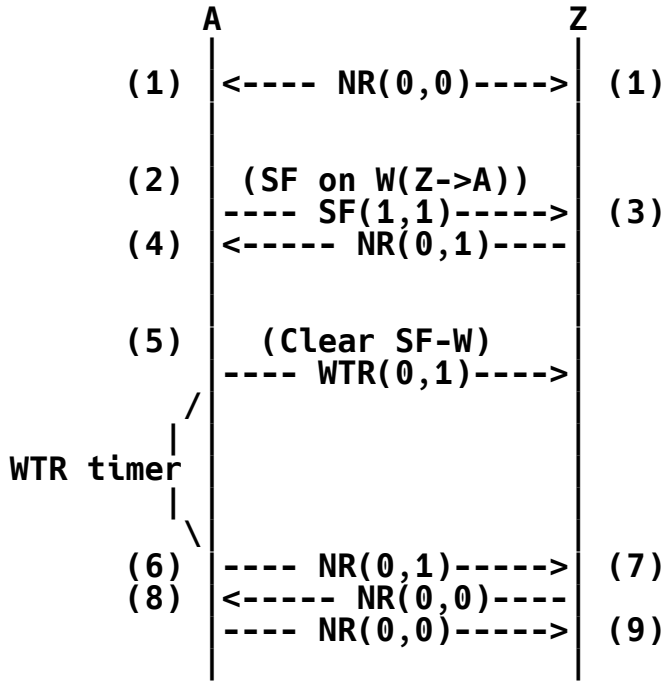
The "Clear Freeze" command clears the local freeze. When the Freeze command is cleared, the state of the protection group is recomputed based on the persistent condition of the local triggers.

Because the freeze is local, if the freeze is issued at one end only, a failure of protocol can occur as the other end is open to accept any operator command or a fault condition.

Appendix D. Operation Examples of the APS Mode

The sequence diagrams shown in this section are only a few examples of the APS mode operations. The first PSC protocol message that differs from the previous message is shown. The operation of the hold-off timer is omitted. The Request, FPath, and Path fields whose values are changed during PSC message exchange are shown. For an example, SF(1,0) represents a PSC message with the following field values: Request=SF, FPath=1, and Path=0. The values of the other fields remain unchanged from the initial configuration. W(A->Z) and P(A->Z) indicate the working path and the protection path in the direction of A to Z, respectively.

Example 1. 1:1 bidirectional protection switching (revertive operation) - Unidirectional SF case



(1) The protected domain is operating without any defect, and the working path is used for delivering the traffic in the Normal state.

(2) SF-W occurs in the Z to A direction. Node A enters into the PF:W:L state and generates an SF(1,1) message. Both the selector and bridge of node A are pointing at the protection path.

(3) Upon receiving an SF(1,1) message, node Z sets both the selector and bridge to the protection path. As there is no local request in node Z, node Z generates an NR(0,1) message in the PF:W:R state.

(4) Node A confirms that the remote node is also selecting the protection path.

(5) Node A detects clearing of SF condition, starts the WTR timer, and sends a WTR(0,1) message in the WTR state.

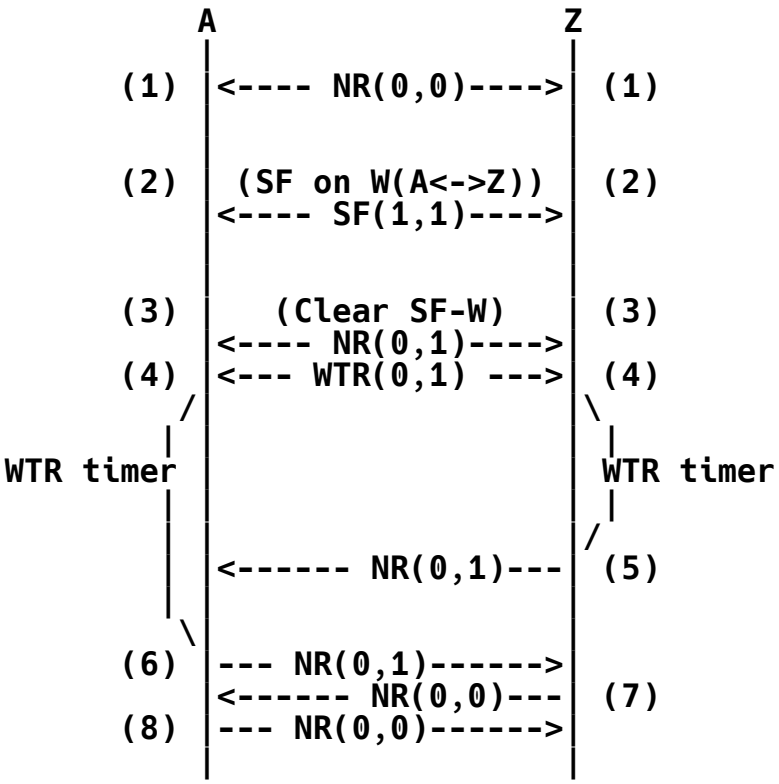
(6) Upon expiration of the WTR timer, node A sets both the selector and bridge to the working path and sends an NR(0,1) message.

(7) Node Z is notified that the remote request has been cleared. Node Z transits to the Normal state and sends an NR(0,0) message.

(8) Upon receiving an NR(0,0) message, node A transits to the Normal state and sends an NR(0,0) message.

(9) It is confirmed that the remote node is also selecting the working path.

Example 2. 1:1 bidirectional protection switching (revertive operation) - Bidirectional SF case - Inconsistent WTR timers



(1) Each end is in the Normal state and transmits NR(0,0) messages.

(2) When SF-W occurs, each node enters into the PF:W:L state and transmits SF(1,1) messages. Traffic is switched to the protection path. Upon receiving an SF(1,1) message, each node confirms that the remote node is also sending and receiving the traffic from the protection path.

(3) When SF-W is cleared, each node transits to the PF:W:R state and transmits NR(0,1) messages as the last received message is SF-W.

(4) Upon receiving NR(0,1) messages, each node goes into the WTR state, starts the WTR timer, and sends the WTR(0,1) messages.

(5) Upon expiration of the WTR timer in node Z, node Z sends an NR(0,1) message as the last received APS message was WTR. When the NR(0,1) message arrives at node A, node A maintains the WTR state and keeps sending current WTR messages as described in the state transition table.

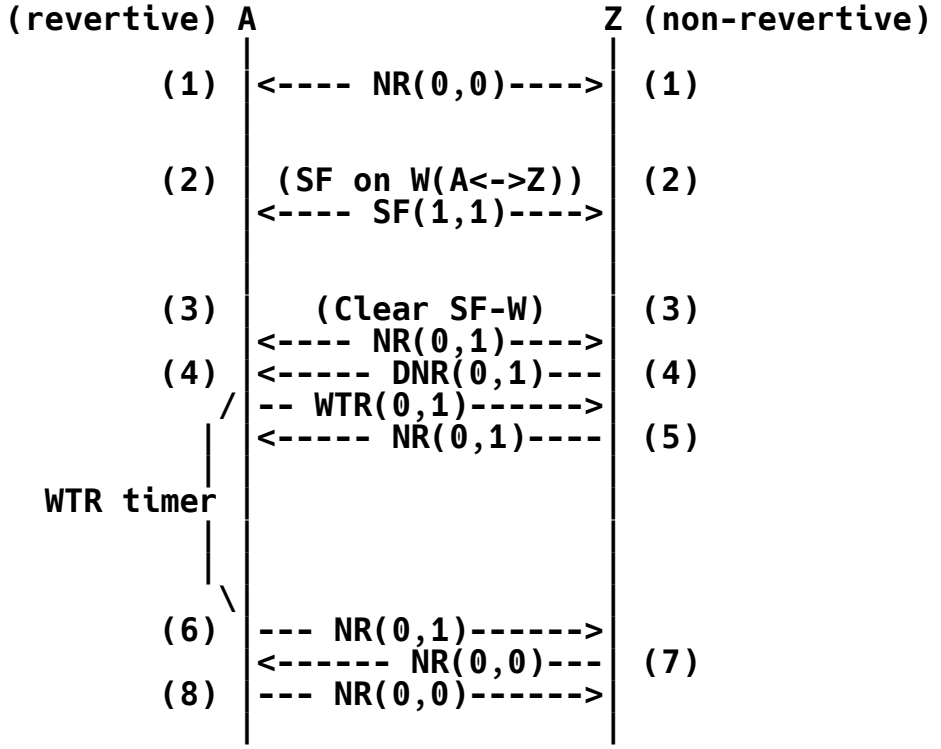
(6) Upon expiration of the WTR timer in node A, node A sends an NR(0,1) message.

(7) When the NR(0,1) message arrives at node Z, node Z moves to the Normal state, sets both the selector and bridge to the working path, and sends an NR(0,0) message.

(8) The received NR(0,0) message causes node A to go to the Normal state. Now, the traffic is switched back to the working path.

Example 3. 1:1 bidirectional protection switching - R bit mismatch

This example shows that both sides will interwork and the traffic is protected when one side (node A) is configured as revertive operation and the other (node Z) is configured as non-revertive operation. The interworking is covered in the state transition tables.



(1) Each end is in the Normal state and transmits NR(0,0) messages.

(2) When SF-W occurs, each node enters into the PF:W:L state and transmits SF(l,l) messages. Traffic is switched to the protection path. Upon receiving an SF(1,1) message, each node confirms that the remote node is also sending and receiving the traffic on the protection path.

(3) When SF-W is cleared, each node transits to the PF:W:R state and transmits NR(0,1) messages as the last received message is SF-W.

(4) Upon receiving NR(0,1) messages, node A goes into the WTR state, starts the WTR timer, and sends WTR(0,1) messages. At the same time, node Z transits to the DNR state and sends a DNR(0,1) message.

(5) When the WTR message arrives at node Z, node Z transits to the WTR state and sends an NR(0,1) message according to the state transition table. At the same time, the DNR message arrived at node Z is ignored according to the state transition table. Therefore, node Z, which is configured as non-revertive operation, is operating as if in revertive operation.

(6) Upon expiration of the WTR timer in node A, node A sends an NR(0,1) message.

(7) When the NR(0,1) message arrives at node Z, node Z moves to the Normal state, sets both the selector and bridge to the working path, and sends an NR(0,0) message.

(8) The received NR(0,0) message causes node A to transit to the Normal state. Now, the traffic is switched back to the working path.

Authors' Addresses

Jeong-dong Ryoo (editor)
ETRI
218 Gajeongno
Yuseong-gu, Daejeon 305-700
South Korea
Phone: +82-42-860-5384
EMail: ryoo@etri.re.kr

Eric Gray (editor)
Ericsson
EMail: eric.gray@ericsson.com

Huub van Helvoort
Huawei Technologies
Karspeldreef 4,
Amsterdam 1101 CJ
The Netherlands
Phone: +31 20 4300936
EMail: huub.van.helvoort@huawei.com

Alessandro D'Alessandro
Telecom Italia
via Reiss Romoli, 274
Torino 10148
Italy
Phone: +39 011 2285887
EMail: alessandro.dalessandro@telecomitalia.it

Taesik Cheung
ETRI
218 Gajeongno
Yuseong-gu, Daejeon 305-700
South Korea
Phone: +82-42-860-5646
EMail: cts@etri.re.kr

Eric Osborne
EMail: eric.osborne@notcom.com