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NAT/FW NSLP State Machine
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Abstract

This document describes the state machines for the NSIS Signaling Layer Protocol for Network Address Translation/Firewall signaling

(NAT/FW NSLP). A set of state machines for NAT/FW NSLP entities at different locations of a signaling path are presented in order to illustrate how NAT/FW NSLP may be implemented.

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[1.](#) Introduction

This document describes the state machines for NAT/FW NSLP [\[1\]](#), trying to show how NAT/FW NSLP can be implemented to support its deployment. The state machines described in this document are illustrative of how the NAT/FW NSLP protocol defined in [\[1\]](#) may be implemented for the first NAT/FW NSLP node in the signaling path, intermediate NAT/FW NSLP nodes with Firewall and/or NAT functionality, and the last NAT/FW NSLP node in the signaling path. Where there are differences [\[1\]](#) are authoritative. The state machines are informative only. Implementations may achieve the same results using different methods.

The messages used in the NAT/FW NSLP protocol can be summarized as follows:

Requesting message	Responding message
-----+-----	
CREATE	RESPONSE
REA	RESPONSE
TRACE	RESPONSE
RESPONSE	NONE
NOTIFY	NONE
-----+-----	

We describe a set of state machines for different roles of entities running NAT/FW NSLP to illustrate how NAT/FW NSLP may be implemented.

[2.](#) Terminology

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 [\[2\]](#).

[3.](#) Notational conventions used in state diagrams

The following state transition tables are completed mostly based on the conventions specified in [\[3\]](#). The complete text is described below.

State transition tables are used to represent the operation of the protocol by a number of cooperating state machines each comprising a group of connected, mutually exclusive states. Only one state of each machine can be active at any given time.

All permissible transitions from a given state to other states and

associated actions performed when the transitions occur are represented by using triplets of (exit condition, exit action, exit state). All conditions are expressions that evaluate to TRUE or FALSE; if a condition evaluates to TRUE, then the condition is met. A state "ANY" is a wildcard state that matches the current state in each state machine. The exit conditions of a wildcard state are evaluated after all other exit conditions of specific to the current state are met.

On exit from a state, the procedures defined for the state and the exit condition are executed exactly once, in the order that they appear on the page. (Note that the procedures defined in [\[4\]](#) are executed on entry to a state, which is one major difference from this document.) Each procedure is deemed to be atomic; i.e., execution of a procedure completes before the next sequential procedure starts to execute. No procedures execute outside of a state block. The procedures in only one state block execute at a time, even if the conditions for execution of state blocks in different state machines are satisfied, and all procedures in an executing state block complete execution before the transition to and execution of any other state block occurs, i.e., the execution of any state block appears to be atomic with respect to the execution of any other state block and the transition condition to that state from the previous state is TRUE when execution commences. The order of execution of state blocks in different state machines is undefined except as constrained by their transition conditions. A variable that is set to a particular value in a state block retains this value until a subsequent state block executes a procedure that modifies the value.

On completion of the transition from the previous state to the current state, all exit conditions for the current state (including exit conditions defined for the wildcard state) are evaluated continuously until one of the conditions is met.

Any event variable is set to TRUE when the corresponding event occurs and set to FALSE immediately after completion of the action associated with the current state and the event.

The interpretation of the special symbols and operators is reused from [4] and the state diagrams are based on the conventions specified in [5], Section 8.2.1.

The complete text is reproduced here:

State diagrams are used to represent the operation of the protocol by a number of cooperating state machines each comprising a group of connected, mutually exclusive states. Only one state of each

machine can be active at any given time.

All permissible transitions between states are represented by arrows, the arrowhead denoting the direction of the possible transition. Labels attached to arrows denote the condition(s) that must be met in order for the transition to take place. All conditions are expressions that evaluate to TRUE or FALSE; if a condition evaluates to TRUE, then the condition is met. The label UCT denotes an unconditional transition (i.e., UCT always evaluates to TRUE). A transition that is global in nature (i.e., a transition that occurs from any of the possible states if the condition attached to the arrow is met) is denoted by an open arrow; i.e., no specific state is identified as the origin of the transition. When the condition associated with a global transition is met, it supersedes all other exit conditions including UCT. The special global condition BEGIN supersedes all other global conditions, and once asserted remains asserted until all state blocks have executed to the point that variable assignments and other consequences of their execution remain unchanged.

On entry to a state, the procedures defined for the state (if any)

are executed exactly once, in the order that they appear on the page. Each action is deemed to be atomic; i.e., execution of a procedure completes before the next sequential procedure starts to execute. No procedures execute outside of a state block. The procedures in only one state block execute at a time, even if the conditions for execution of state blocks in different state machines are satisfied, and all procedures in an executing state block complete execution before the transition to and execution of any other state block occurs, i.e., the execution of any state block appears to be atomic with respect to the execution of any other state block and the transition condition to that state from the previous state is TRUE when execution commences. The order of execution of state blocks in different state machines is undefined except as constrained by their transition conditions. A variable that is set to a particular value in a state block retains this value until a subsequent state block executes a procedure that modifies the value.

On completion of all of the procedures within a state, all exit conditions for the state (including all conditions associated with global transitions) are evaluated continuously until one of the conditions is met. The label ELSE denotes a transition that occurs if none of the other conditions for transitions from the state are met (i.e., ELSE evaluates to TRUE if all other possible exit conditions from the state evaluate to FALSE). Where two or more exit conditions with the same level of precedence become TRUE

simultaneously, the choice as to which exit condition causes the state transition to take place is arbitrary.

In addition to the above notation, there are a couple of clarifications specific to this document. First, all boolean variables are initialized to FALSE before the state machine execution begins. Second, the following notational shorthand is specific to this document:

<variable> = <expression1> | <expression2> | ...

Execution of a statement of this form will result in <variable> having a value of exactly one of the expressions. The logic for which of those expressions gets executed is outside of the state machine and could be environmental, configurable, or based on another state machine such as that of the method.

4. State Machine Symbols

- () Used to force the precedence of operators in Boolean expressions and to delimit the argument(s) of actions within state boxes.
- ; Used as a terminating delimiter for actions within state boxes. Where a state box contains multiple actions, the order of execution follows the normal language conventions for reading text.
- = Assignment action. The value of the expression to the right of the operator is assigned to the variable to the left of the operator. Where this operator is used to define multiple assignments, e.g., a = b = X the action causes the value of the expression following the right-most assignment operator to be assigned to all of the variables that appear to the left of the right-most assignment operator.
- ! Logical NOT operator.
- && Logical AND operator.
- || Logical OR operator.
- if...then... Conditional action. If the Boolean expression following the if evaluates to TRUE, then the action following the then is executed.
- { statement 1, ... statement N } Compound statement. Braces are used to group statements that are executed together as if they were a single statement.
- != Inequality. Evaluates to TRUE if the expression to the left of the operator is not equal in value to the expression to the right.
- == Equality. Evaluates to TRUE if the expression to the left of the operator is equal in value to the expression to the right.

- > Greater than. Evaluates to TRUE if the value of the expression to the left of the operator is greater than the value of the expression to the right.
- <= Less than or equal to. Evaluates to TRUE if the value of the expression to the left of the operator is either less than or equal to the value of the expression to the right.
- ++ Increment the preceding integer operator by 1.

[5.](#) Common Rules

Throughout the document we use terms defined in the [\[1\]](#), such as NI, NF, NR, CREATE, REA or RESPONSE.

[5.1.](#) Common Procedures

`tx_CREATE()`: Transmit a CREATE message
`tx_CREATE(LIFETIME>0)`: Transmit CREATE message with lifetime object greater than 0 for session creation.
`tx_CREATE(LIFETIME=0)`: Transmit CREATE message with lifetime object explicitly set to 0 for session deletion.
`tx_RESPONSE(code,type)`: Transmit RESPONSE message with specified code (SUCCESS or ERROR) and result type (related to a specific request type message: CREATE or REA). A code or result type may be omitted, typically when forwarding received RESPONSE messages.
`tx_REA()`: Transmit a REA message
`rx_RESPONSE(code, type)`: Evaluates to TRUE if a RESPONSE message has been received with the specified code (SUCCESS or ERROR) and result type (related to a specific request type message: CREATE or REA). If the code or type is omitted, any received RESPONSE message which is only matching the given code or type will evaluate this procedure to TRUE.
`rx_CREATE()`: Evaluates to TRUE if a CREATE message has been received.
`rx_CREATE(Lifetime > 0)`: Evaluates to TRUE if a CREATE message with lifetime object greater than 0 has been received.
`rx_CREATE(Lifetime == 0)`: Evaluates to TRUE if a CREATE message with lifetime object explicitly set to 0 has been received.
`rx_REA()`: Evaluates to TRUE if a REA message has been received.
`rx_REA(Lifetime > 0)`: Evaluates to TRUE if a REA message with lifetime object greater than 0 has been received.
`rx_REA(Lifetime == 0)`: Evaluates to TRUE if a REA message with lifetime object explicitly set to 0 has been received.
`CHECK_AA()`: Checks Authorization and Authentication of the received message. Evaluates to TRUE if the check is successful, otherwise it evaluates to FALSE. This check is performed on all received messages hence it will only be shown within the state machine when the check has failed. This CHECK_AA also MAY include a local policy check for the received message.

`CreateSession()`: Installs all session related states, variables,

bindings, policies.

DeleteSession(): Removes all session related states, variables, bindings, policies.

CreatePinhole(): Installs a pinhole for the new session.

DeletePinhole(): Removes a previously installed pinhole.

CreateReservations(): Creates a matching based on the MRI and open pinholes for the signaling traffic.

DeleteReservations(): Deletes previously installed matchings and pinholes for the signaling traffic.

CreateBinding(): Creates a public/private network translation binding on a NAT device for the requesting entity.

DeleteBinding(): Deletes a previously created a public/private network translation binding on a NAT device for the requesting entity.

StartTimer(identifier): This procedure starts a timer with a certain timespan, which is up to the specific implementation. The parameter 'identifier' identifies this timer uniquely. Any subsequent StartTimer(identifier), StopTimer(identifier), (identifier)_TIMEOUT refer to the same timer labeled x. This timer is required to time the lifetime of state, which means that when it times out, it indicates the current machine state should be left or its validation has expired. This procedure starts the timer 'identifier'. If a timer with the same 'identifier' has already been started and not yet stopped, the timer is now stopped and restarted. After the timer has timed out, the procedure (identifier)_TIMEOUT evaluates to TRUE. The timer does not restart automatically, but must be started again with a StartTimer(identifier). Used identifier are STATE, REFRESH, CREATE, REA or RESPONSE.

StopTimer(identifier): This procedure stops the timer labeled 'identifier'. If it has already been stopped, this procedure has no effect. If the timer has already timed out, this procedure removes the timeout-state from the timer 'identifier', so subsequent calls to (identifier)_TIMEOUT evaluate to FALSE. A timeout cannot occur until the timer 'identifier' has been (re-)started.

(identifier)_TIMEOUT: This procedure evaluates to TRUE if the (identifier)-timer has timed out and indicates a state lifetime expiration. This procedure cannot evaluate to TRUE if the timer has been stopped. Used timers are STATE_TIMEOUT, REFRESH_TIMEOUT, CREATE_TIMEOUT, REA_TIMEOUT or RESPONSE_TIMEOUT.

tg_CREATE: External trigger to send a CREATE message (typically triggered by the application).

tg_TEARDOWN: External trigger to delete a previously created session (typically triggered by the application)
tg_REA: External trigger to send a REA message towards an opportunistic address (typically triggered by the application)
tg_CREATE_PROXY: Internal trigger to send a CREATE message (used in proxy mode, triggered by corresponding NAT/FW NSLP session).
tg_TEARDOWN_PROXY: Internal trigger to delete a previously created session (used in proxy mode, triggered by corresponding NAT/FW NSLP session).

[5.2.](#) Common Variables

IS_EDGE: Boolean flag which evaluates to TRUE if the node is on the network edge, otherwise it evaluates to FALSE.
IS_PUBLICSIDE: Boolean flag which evaluates to TRUE if the (CREATE- or REA-) message has been received on the public side of the network.
CREATE(LIFETIME): Gets the value of the LIFETIME object in the CREATE message.
counter(CREATE): Denotes the current number of retries of CREATE message which has been re-transmitted due to previous RESPONSE_ERROR message. If the number of counter(CREATE) equals the value of counterLimit(CREATE), the current session creation attempt is aborted and the application is being notified.
counter(REA): Denotes the current number of retries of REA message which has been re-transmitted due to previous RESPONSE_ERROR message. If the number of counter(REA) equals the value of counterLimit(REA), the current session creation attempt is aborted and the application is being notified.

[5.3.](#) Constants

counterLimit(CREATE): Contains the maximum number of retransmission attempts of a CREATE message after it is aborted and the application is being notified.
counterLimit(REA): Contains the maximum number of retransmission attempts of a REA message after it is aborted and the application is being notified.

[6.](#) State machine for the NAT/FW NI/NR+

This section presents the state machine for the NSIS initiator which is capable of NAT/FW NSLP signaling.

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 State: INITIALIZE

Condition	Action	State
UCT	Initialize variables	IDLE

 State: IDLE
 Entry: DeleteSession();
 Exit : CreateSession();

Condition	Action	State
tg_CREATE	tx_CREATE();	WAITRESP
tg_CREATE_PROXY	tx_CREATE();	WAITRESP

 State: WAITRESP
 Entry: ResetCounter(CREATE);
 StartTimer(RESPONSE);
 Exit : StopTimer(RESPONSE);

Condition	Action	State
RESPONSE_TIMEOUT && (counter(CREATE) < counterLimit(CREATE))	counter(CREATE)++; StartTimer(RESPONSE); tx_CREATE();	WAITRESP
rx_RESPONSE(SUCCESS, CREATE)	ReportAsyncEvent();	SESSION

tg_TEARDOWN	tx_CREATE(Lifetime=0);	IDLE
tg_TEARDOWN_PROXY	tx_CREATE(Lifetime=0);	IDLE
RESPONSE_TIMEOUT && (counter(CREATE)== counterLimit(CREATE))	ReportAsyncEvent();	IDLE
rx_RESPONSE(ERROR,CREATE)	ReportAsyncEvent();	IDLE

-----+-----+-----

State: SESSION
Entry: ResetCounter(CREATE);
 StartTimer(REFRESH);
Exit : StopTimer(REFRESH);
 StopTimer(RESPONSE);

Condition	Action	State
REFRESH_TIMEOUT	StartTimer(RESPONSE); tx_CREATE();	SESSION
RESPONSE_TIMEOUT && (counter(CREATE) < counterLimit(CREATE))	counter(CREATE)++; StartTimer(RESPONSE); tx_CREATE();	SESSION
rx_RESPONSE(SUCCESS,CREATE)	StopTimer(RESPONSE); StartTimer(REFRESH); ResetCounter(CREATE);	SESSION
tg_TEARDOWN	tx_CREATE(LIFETIME=0);	IDLE
tg_TEARDOWN_PROXY	tx_CREATE(LIFETIME=0);	IDLE
RESPONSE_TIMEOUT && (counter(CREATE) == counterLimit(CREATE))	ReportAsyncEvent();	IDLE

rx_RESPONSE(ERROR,CREATE)	ReportAsyncEvent();	IDLE
-----+-----+-----		

7. State machine for the NAT/FW NF

This section describes the state machine for intermediate nodes within the signaling path capable of processing NAT/FW NSLP messages. These nodes typically implement firewall and/or network address translation (NAT) functionality.

Condition	Action	State
UCT	Initialize variables	IDLE

-----+-----+-----		
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```

-----
State: IDLE
Entry: DeleteSession();
Exit : CreateSession();
-----

```

Condition	Action	State
(rx_REA) && (IS_PUBLICSIDE)	tx_RESPONSE(ERROR, REA);	IDLE
(rx_CREATE(Lifetime > 0))	tx_CREATE();	CREATE_
		WAITRESP
((rx_REA) && (!IS_EDGE) && (!IS_PUBLICSIDE))	tx_REA();	NONEDGE_
		REA
((rx_REA) && (IS_EDGE) && (!IS_PUBLICSIDE))	tx_RESPONSE(SUCCESS, REA);	EDGE_REA
	tx_CREATE;	
	if(proxy_object) then	
	(tg_CREATE_PROXY);	
-----+-----+-----		

State: CREATE_WAITRESP
Entry: StartTimer(STATE);
Exit : StopTimer(STATE);

Condition	Action	State
rx_RESPONSE(ERROR,CREATE)	tx_RESPONSE(ERROR,CREATE); ReportAsyncEvent();	IDLE
STATE_TIMEOUT	tx_RESPONSE(ERROR,CREATE); ReportAsyncEvent();	IDLE
(rx_CREATE(Lifetime == 0))	tx_CREATE(Lifetime=0);	IDLE
rx_RESPONSE(SUCCESS,CREATE)	tx_RESPONSE(SUCCESS,CREATE);	SESSION

State: NONEDGE_REA
Entry: StartTimer(REA);
 CreateReservations();
Exit : StopTimer(REA);
 DeleteReservations();

Condition	Action	State
(rx_REA(Lifetime > 0))	StopTimer(REA); StartTimer(REA); tx_REA();	NONEDGE_ REA
rx_RESPONSE(SUCCESS, REA)	tx_RESPONSE(SUCCESS, REA); 	NONEDGE_ REA
rx_RESPONSE(ERROR, REA)	tx_RESPONSE(ERROR, REA);	IDLE

	ReportAsyncEvent();	
(rx_REA(Lifetime == 0))	tx_REA(Lifetime=0);	IDLE
	ReportAsyncEvent();	
REA_TIMEOUT	ReportAsyncEvent();	IDLE
-----+-----+-----		

```

-----
State: EDGE_REA
Entry: StartTimer(REA);
      CreateReservations();
Exit : StopTimer(REA);
      DeleteReservations();
-----

```

Condition	Action	State
-----+-----+-----		
(rx_REA(Lifetime > 0))	StopTimer(REA);	EDGE_REA

	StartTimer(REA);	
	tx_RESPONSE(SUCCESS, REA);	
(rx_REA(Lifetime == 0))	tx_REA(Lifetime=0);	IDLE
	ReportAsyncEvent();	
	if(proxy_mode) then	
	(tg_TEARDOWN_PROXY);	
REA_TIMEOUT	ReportAsyncEvent();	IDLE
	if(proxy_mode) then	
	(tg_TEARDOWN_PROXY);	
-----+-----+-----		

State: SESSION
Entry: StartTimer(CREATE)
 CreatePinhole();

```

        CreateBinding();
Exit : StopTimer(RESPONSE);
        StopTimer(CREATE);
        DeletePinhole();
        DeleteBinding();
-----

```

Condition	Action	State
RESPONSE_TIMEOUT	StopTimer(RESPONSE); tx_RESPONSE(ERROR,CREATE);	SESSION
(rx_REA(Lifetime > 0))	StopTimer(CREATE); StartTimer(RESPONSE); tx_CREATE();	SESSION
rx_RESPONSE(SUCCESS,CREATE)	StopTimer(RESPONSE); StartTimer(CREATE); tx_RESPONSE(SUCCESS,CREATE);	SESSION
CREATE_TIMEOUT	ReportAsyncEvent();	IDLE
(rx_REA(Lifetime == 0))	tx_CREATE(Lifetime=0);	IDLE

[8.](#) State machine for the NAT/FW NR/NI+

This section presents the state machines for the NSIS responder which is capable of NSLP NAT/FW signaling.

```

-----
State: INITIALIZE
-----

```

Condition	Action	State
UCT	Initialize variables	IDLE

```

-----
State: IDLE
Entry: DeleteSession();
Exit : CreateSession();
-----

```

Condition	Action	State
(rx_CREATE) && !(CHECK_AA())	tx_RESPONSE(ERROR,CREATE);	IDLE
tg_REA	tx_REA();	REA_ WAITRESP
(rx_REA(Lifetime > 0))	tx_RESPONSE(SUCCESS,CREATE);	SESSION

```

-----
State: REA_WAITRESP
Entry: ResetCounter(REA);
      StartTimer(RESPONSE);
Exit : StopTimer(RESPONSE);
-----

```

Condition	Action	State
RESPONSE_TIMEOUT && (counter(REA) < counterLimit(REA))	counter(REA)++; StartTimer(RESPONSE); tx_REA();	REA_ WAITRESP
rx_RESPONSE(SUCCESS,REA)	ReportAsyncEvent();	REA
RESPONSE_TIMEOUT && (counter(REA) == counterLimit(REA))	ReportAsyncEvent();	IDLE
rx_RESPONSE(ERROR,REA)	ReportAsyncEvent();	IDLE
tg_TEARDOWN	tx_REA(Lifetime=0);	IDLE

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```

-----
State: REA
Entry: ResetCounter(REA);
      StartTimer(REFRESH);
Exit : StopTimer(RESPONSE);
      StopTimer(REFRESH);
-----

```

Condition	Action	State
RESPONSE_TIMEOUT && (counter(REA) < counterLimit(REA))	counter(REA)++; StartTimer(RESPONSE); tx_REA();	REA
rx_RESPONSE(SUCCESS, REA)	StartTimer(REFRESH); StopTimer(RESPONSE); ResetCounter(REA);	REA
REFRESH_TIMEOUT	tx_REA(); StartTimer(RESPONSE);	REA
RESPONSE_TIMEOUT && (counter(REA) == counterLimit(REA))	ReportAsyncEvent();	IDLE
rx_RESPONSE(ERROR, REA)	ReportAsyncEvent();	IDLE
tg_TEARDOWN	tx_REA(Lifetime=0);	IDLE

```

-----
State: SESSION
Entry: StartTimer(STATE);
Exit : StopTimer(STATE);
-----

```

Condition	Action	State
(rx_CREATE(LIFETIME > 0))	tx_RESPONSE(SUCCESS, CREATE);	SESSION

	StopTimer(STATE);	
	StartTimer(STATE);	
(rx_CREATE(LIFETIME == 0))	ReportAsyncEvent();	IDLE
STATE_TIMEOUT	ReportAsyncEvent();	IDLE
-----+-----+-----		

[9.](#) Security Considerations

This document does not raise new security considerations. Any security concerns with the NAT/FW NSLP are likely reflected in security related NSIS work already (such as [\[1\]](#) or [\[6\]](#)).

For the time being, the state machines described in this document do not consider the security aspect of NAT/FW NSLP protocol itself. A future version of this document will add security relevant states and state transitions.

[10.](#) Open Issues

Since 01 version, we removed session ownership, change procedure-names and added some clarifications according to the specification evolution. Route change and the open issues in [\[1\]](#) will be added in future versions of this document.

[11.](#) Contributors

Tseno Tsenov contributed since the initial version and Henning Peters collaborated to refining of the state machine since 01 version.

[12.](#) Acknowledgments

The authors would like to thank Martin Stiernerling for his valuable comments and discussions.

[13.](#) References

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