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Software-Defined Networking (SDN)-based IPsec Flow Protection
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Abstract

This document describes how to provide IPsec-based flow protection (integrity and confidentiality) by means of an I2NSF Controller. It considers two main well-known scenarios in IPsec: (i) gateway-to-gateway and (ii) host-to-host. The service described in this document allows the configuration and monitoring of IPsec information from a I2NSF Controller to one or several flow-based Network Security Function (NSF) that implement IPsec to protect data traffic.

The document focuses on the I2NSF NSF-Facing Interface by providing YANG data models for configuration and state data required to allow the I2NSF Controller to configure the IPsec databases (SPD, SAD, PAD) and IKEv2 to establish IPsec Security Associations with a reduced intervention of the network administrator.

Status of This Memo

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[1](#). Introduction

Software-Defined Networking (SDN) is an architecture that enables users to directly program, orchestrate, control and manage network resources through software. The SDN paradigm relocates the control of network resources to a centralized entity, namely SDN Controller. The SDN controller manages and configures the distributed network resources and provides an abstracted view of the network resources to the SDN applications. The SDN application can customize and automate the operations (including management) of the abstracted network resources in a programmable manner via this interface [[RFC7149](#)] [[ITU-T.Y.3300](#)] [[ONF-SDN-Architecture](#)] [[ONF-OpenFlow](#)].

Recently, several network scenarios are demanding a centralized way of managing different security aspects. For example, Software-Defined WANs (SD-WAN), an SDN extension providing a software abstraction to create secure network overlays over traditional WAN and branch networks. SD-WAN is based on IPsec [[RFC4301](#)] as an underlying security protocol and aims to provide flexible, automated, and rapid deployment, enabling on-demand security network services, such as IPsec Security Association (IPsec SA) management, from a centralized point. Additionally, [Section 4.3.3 in \[RFC8192\]](#) describes another example, a use case for Cloud Data Center Scenario, entitled Client-Specific Security Policy in Cloud VPNs, where "the dynamic key management is critical for securing the VPN and the distribution of policies". These VPNs can be established using IPsec. The management of IPsec SAs in data centers using a centralized entity is also an scenario of interest.

Therefore, with the growth of SDN-based scenarios where network resources are deployed in an autonomous manner, a mechanism to manage IPsec SAs from a centralized entity becomes more relevant in the industry.

In response to this need, the Interface to Network Security Functions (I2NSF) charter states that the goal of this working group is "to define set of software interfaces and data models for controlling and monitoring aspects of physical and virtual Network Security Functions". As defined in [[RFC8192](#)] an NSF is "a function that is used to ensure integrity, confidentiality, or availability of network

communication; to detect unwanted network activity; or to block, or at least mitigate, the effects of unwanted activity". This document pays special attention to flow-based NSFs that ensure integrity and confidentiality by means of IPsec.

In fact, as [Section 3.1.9 in \[RFC8192\]](#) states "there is a need for a controller to create, manage, and distribute various keys to distributed NSFs.", however "there is a lack of a standard interface to provision and manage security associations". Inspired in the SDN paradigm, the I2NSF framework [\[RFC8329\]](#) defines a centralized entity, the I2NSF Controller, which manages one or multiple NSFs through a I2NSF NSF-Facing interface. In this document we define a service allowing the I2NSF Controller to carry out the key management procedures. More specifically, we define YANG data models for I2NSF NSF-Facing interface that allow the I2NSF Controller to configure and monitor IPsec-enabled flow-based NSFs.

IPsec architecture [\[RFC4301\]](#) defines clear separation between the processing to provide security services to IP packets and the key management procedures to establish the IPsec Security Associations, which allows to centralize the key management procedures in the I2NSF Controller. This document considers two typical scenarios to autonomously manage IPsec SAs: gateway-to-gateway and host-to-host [\[RFC6071\]](#). In these cases, hosts, gateways or both may act as NSFs. Consideration for the host-to-gateway scenario is out of scope.

For the definition of the YANG data model for I2NSF NSF-Facing interface, this document considers two general cases, namely:

- 1) IKE case. The NSF implements the Internet Key Exchange version 2 (IKEv2) protocol and the IPsec databases: the Security Policy Database (SPD), the Security Association Database (SAD) and the Peer Authorization Database (PAD). The I2NSF Controller is in charge of provisioning the NSF with the required information in the SPD, PAD (e.g. IKE credential) and IKE protocol itself (e.g. parameters for the IKE_SA_INIT negotiation).
- 2) IKE-less case. The NSF only implements the IPsec databases (no IKE implementation). The I2NSF Controller will provide the required parameters to create valid entries in the SPD and the SAD into the NSF. Therefore, the NSF will have only support for IPsec while key management functionality is moved to the I2NSF Controller.

In both cases, a data model for the I2NSF NSF-Facing interface is required to carry out this provisioning in a secure manner between the I2NSF Controller and the NSF. Based on YANG models in [\[netconf-vpn\]](#) and [\[I-D.tran-ipsecme-yang\]](#), [RFC 4301](#) [\[RFC4301\]](#) and RFC

7296 [[RFC7296](#)], this document defines the required interfaces with a YANG model for configuration and state data for IKE, PAD, SPD and SAD (see [Appendix A](#), [Appendix B](#) and [Appendix C](#)). Examples of the usage of these models can be found in [Appendix D](#), [Appendix E](#) and [Appendix F](#).

In summary, the objectives of this I-D are:

- o To describe the architecture for the I2NSF-based IPsec management, which allows the establishment and management of IPsec security associations from the I2NSF Controller in order to protect specific data flows between two flow-based NSFs implementing IPsec.
- o To map this architecture to the I2NSF Framework.
- o To define the interfaces required to manage and monitor the IPsec SAs in the NSF from a I2NSF Controller. YANG data models are defined for configuration and state data for IPsec and IKEv2 management through the I2NSF NSF-Facing interface.

2. Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [RFC 2119](#) [[RFC2119](#)]. When these words appear in lower case, they have their natural language meaning.

3. Terminology

This document uses the terminology described in [[RFC8329](#)], [[RFC8192](#)], [[RFC4301](#)], [[RFC7296](#)], [[RFC6241](#)], [[ITU-T.Y.3300](#)]. The following term is defined in [[ITU-T.Y.3300](#)]:

- o Software-Defined Networking.

The following terms are in defined in [[RFC8192](#)]:

- o NSF.
- o Flow-based NSF.

The following terms are defined in [[RFC4301](#)]:

- o Peer Authorization Database (PAD).
- o Security Associations Database (SAD).

- o Security Policy Database (SPD).

The following term is defined in [[RFC6437](#)]:

- o Flow/traffic flow.

The following terms is defined in [[RFC7296](#)]:

- o Internet Key Exchange version 2 (IKEv2).

The following terms are defined in [[RFC6241](#)]:

- o Configuration data.
- o Configuration datastore.
- o State data.
- o Startup configuration datastore.
- o Running configuration datastore.

4. SDN-based IPsec management description

As mentioned in [Section 1](#), two cases are considered, depending on whether the NSF ships an IKEv2 implementation or not: IKE case and IKE-less case.

4.1. IKE case: IKEv2/IPsec in the NSF

In this case, the NSF ships an IPsec implementation with IKEv2 support. The I2NSF Controller is in charge of managing and applying IPsec connection information (determining which nodes need to start an IKEv2/IPsec session, identifying the type of traffic to be protected, deriving and delivering IKEv2 Credentials such as a pre-shared key, certificates, etc.), and applying other IKEv2 configuration parameters (e.g. cryptographic algorithms for establishing an IKEv2 SA) to the NSF necessary for the IKEv2 negotiation.

With these entries, the IKEv2 implementation can operate to establish the IPsec SAs. The I2NSF User establishes the IPsec requirements and information about the end points information (through the I2NSF Consumer-Facing Interface, [[RFC8329](#)]), and the I2NSF Controller translates these requirements into IKEv2, SPD and PAD entries that will be installed into the NSF (through the I2NSF NSF-Facing Interface). With that information, the NSF can just run IKEv2 to establish the required IPsec SA (when the traffic flow needs

protection). Figure 1 shows the different layers and corresponding functionality.

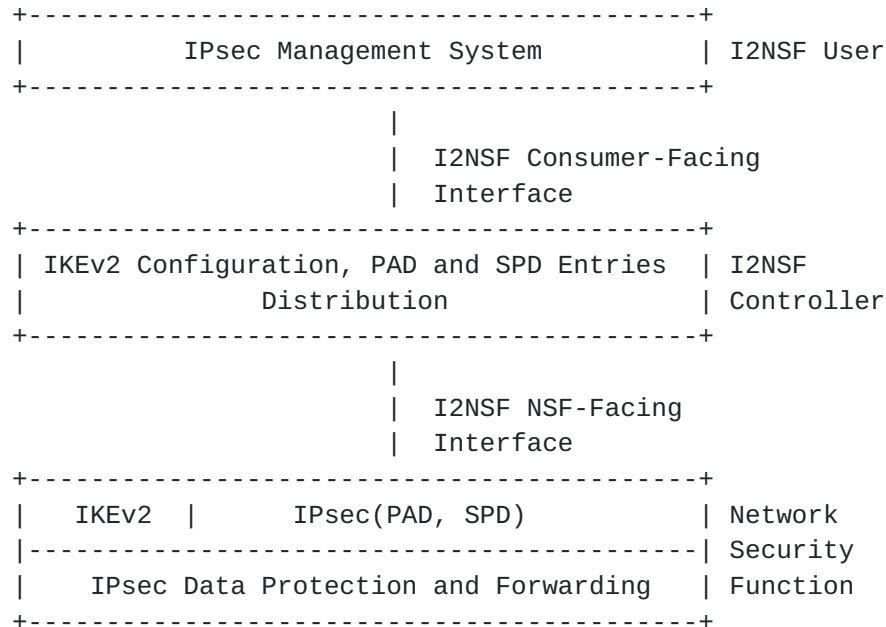


Figure 1: IKE case: IKE/IPsec in the NSF

I2NSF-based IPsec flow protection services provide dynamic and flexible management of IPsec SAs in flow-based NSFs. In order to support this capability in the IKE case, a YANG data model for IKEv2, SPD and PAD configuration data, and for IKEv2 state data MUST be defined for the I2NSF NSF-Facing Interface.

4.2. IKE-less case: IPsec (no IKEv2) in the NSF.

In this case, the NSF does not deploy IKEv2 and, therefore, the I2NSF Controller has to perform the IKEv2 security functions and management of IPsec SAs by populating and managing the SPD and the SAD.

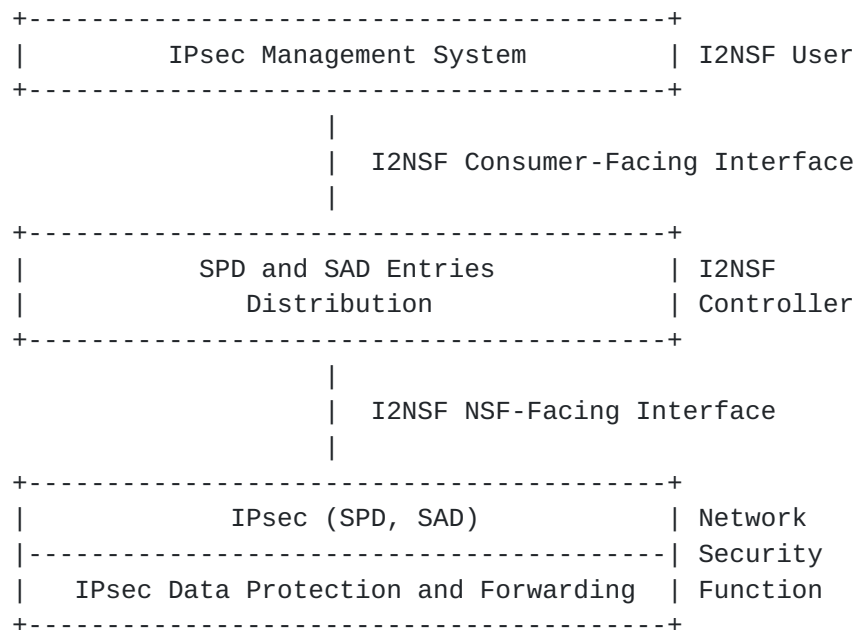


Figure 2: IKE-less case: IPsec (no IKEv2) in the NSF

As shown in Figure 2, when an I2NSF User enforces flow-based protection policies through the Consumer-Facing Interface, the I2NSF Controller translates these requirements into SPD and SAD entries, which are installed in the NSF. PAD entries are not required since there is no IKEv2 in the NSF.

In order to support the IKE-less case, a YANG data model for SPD and SAD configuration data and SAD state data MUST be defined for the NSF-Facing Interface.

Specifically, the IKE-less case assumes that the I2NSF Controller has to perform some security functions that IKEv2 typically does, namely (non-exhaustive):

- o IV generation.
- o Prevent counter resets for the same key.
- o Generation of pseudo-random cryptographic keys for the IPsec SAs.
- o Generation of the IPsec SAs when required based on notifications (i.e. sadb-acquire) from the NSF.
- o Rekey of the IPsec SAs based on notifications from the NSF (i.e. expire).

- o NAT Traversal discovery and management.

Additionally to these functions, another set of tasks must be performed by the I2NSF Controller (non-exhaustive list):

- o IPsec SA's SPI random generation.
- o Cryptographic algorithm/s selection.
- o Usage of extended sequence numbers.
- o Establishment of proper traffic selectors.

5. IKE case vs IKE-less case

In principle, the IKE case is easier to deploy than the IKE-less case because current flow-based NSFs (either hosts or gateways) have access to IKEv2 implementations. While gateways typically deploy an IKEv2/IPsec implementation, hosts can easily install it. As downside, the NSF needs more resources to hold IKEv2 such as memory for the IKEv2 implementation, and computation, since each IPsec security association rekeying MAY involve a Diffie-Hellman exchange.

Alternatively, IKE-less case benefits the deployment in resource-constrained NSFs. Moreover, IKEv2 does not need to be performed in gateway-to-gateway and host-to-host scenarios under the same I2NSF Controller (see [Appendix G.1](#)). On the contrary, the complexity of creating and managing IPsec SAs is shifted to the I2NSF Controller since IKEv2 is not in the NSF. As a consequence, this may result in a more complex implementation in the controller side in comparison with IKE case. For example, the I2NSF Controller has to deal with the latency existing in the path between the I2NSF Controller and the NSF, in order to solve tasks such as rekey, or creation and installation of new IPsec SAs. However, this is not specific to this contribution but a general aspect in any SDN-based network. In summary, this complexity MAY create some scalability and performance issues when the number of NSFs is high.

Nevertheless, literature around SDN-based network management using a centralized controller (like the I2NSF Controller) is aware about scalability and performance issues and solutions have been already provided and discussed (e.g. hierarchical controllers; having multiple replicated controllers, dedicated high-speed management networks, etc). In the context of I2SNF-based IPsec management, one way to reduce the latency and alleviate some performance issues can be the installation of the IPsec policies and IPsec SAs at the same time (proactive mode, as described in [Appendix G.1](#)) instead of waiting for notifications (e.g. a notification `sadb-acquire` when a

new IPsec SA is required) to proceed with the IPsec SA installation (reactive mode). Another way to reduce the overhead and the potential scalability and performance issues in the I2NSF Controller is to apply the IKE case described in this document, since the IPsec SAs are managed between NSFs without the involvement of the I2NSF Controller at all, except by the initial configuration (i.e. IKEv2, PAD and SPD entries) provided by the I2NSF Controller. Other solutions, such as Controller-IKE

[[I-D.carrel-ipsecme-controller-ike](#)], have proposed that NSFs provide their DH public keys to the I2NSF Controller, so that the I2NSF Controller distributes all public keys to all peers. All peers can calculate a unique pairwise secret for each other peer and there is no inter-NSF messages. A rekey mechanism is further described in [[I-D.carrel-ipsecme-controller-ike](#)].

In terms of security, IKE case provides better security properties than IKE-less case, as we discuss in section [Section 8](#). The main reason is that the NSFs generate the session keys and not the I2NSF Controller.

[5.1. Rekeying process](#)

Performing a rekey for IPsec SAs is an important operation during the IPsec SAs management. With the YANG data models defined in this document the I2NSF Controller can configure and conduct the rekey process. Depending on the case, the rekey process is different.

For the IKE case, the rekeying process is carried out by IKEv2, following the information defined in the SPD and SAD (i.e. based on the IPsec SA lifetime established by the I2NSF Controller using the YANG data model defined in this document). Therefore, IPsec connections will live unless something different is required by the I2NSF User or the I2NSF Controller detects something wrong.

For the IKE-less case, the I2NSF Controller MUST take care of the rekeying process. When the IPsec SA is going to expire (e.g. IPsec SA soft lifetime), it MUST create a new IPsec SA and it MAY remove the old one (if a IPsec SA lifetime has not been defined). This rekeying process starts when the I2NSF Controller receives a sadb-expire notification or it decides so, based on lifetime state data obtained from the NSF. How the I2NSF Controller implements an algorithm for the rekey process is out of the scope of this document. Nevertheless, an example of how this rekey could be performed is in [Appendix G.2](#).

5.2. NSF state loss.

If one of the NSF restarts, it will lose the IPsec state (affected NSF). By default, the I2NSF Controller can assume that all the state has been lost and therefore it will have to send IKEv2, SPD and PAD information to the NSF in the IKE case, and SPD and SAD information in the IKE-less case.

In both cases, the I2NSF Controller is aware of the affected NSF (e.g. the NETCONF/TCP connection is broken with the affected NSF, the I2NSF Controller is receiving sadb-bad-spi notification from a particular NSF, etc.). Moreover, the I2NSF Controller keeps a list of NSFs that have IPsec SAs with the affected NSF. Therefore, it knows the affected IPsec SAs.

In the IKE case, the I2NSF Controller will configure the affected NSF with the new IKEv2, SPD and PAD information. It has also to send new parameters (e.g. a new fresh PSK for authentication) to the NSFs which have IKEv2 SAs and IPsec SAs with the affected NSF. Finally, the I2NSF Controller will instruct the affected NSF to start the IKEv2 negotiation with the new configuration.

Alternatively, IKEv2 configuration MAY be made permanent between NSFs reboots without compromising security by means of the startup configuration datastore in the NSF. This way, each time a NSF reboots it will use that configuration for each rebooting. It would imply avoiding to contact with the I2NSF Controller.

In the IKE-less case, the I2NSF Controller SHOULD delete the old IPsec SAs in the non-failed nodes established with the affected NSF. Once the affected node restarts, the I2NSF Controller MUST take the necessary actions to reestablish IPsec protected communication between the failed node and those others having IPsec SAs with the affected NSF. How the I2NSF Controller implements an algorithm for managing a potential NSF state loss is out of the scope of this document. Nevertheless, an example of how this could be performed is described in [Appendix G.3](#).

5.3. NAT Traversal

In the IKE case, IKEv2 already provides a mechanism to detect whether some of the peers or both are located behind a NAT. If there is a NAT network configured between two peers, it is required to activate the usage of UDP or TCP/TLS encapsulation for ESP packets ([[RFC3948](#)], [[RFC8229](#)]). Note that the usage of IPsec transport mode when NAT is required MUST NOT be used in this specification.

In the IKE case, IKEv2 already provides a mechanism to detect whether some of the peers or both are located behind a NAT. If there is a NAT network configured between two peers, it is required to activate the usage of UDP or TCP/TLS encapsulation for ESP packets ([RFC3948], [RFC8229]). Note that the usage of IPsec transport mode when NAT is required MUST NOT be used in this specification.

In the IKE-less case, the NSF does not have the assistance of the IKEv2 implementation to detect if it is located behind a NAT. If the NSF does not have any other mechanism to detect this situation, the I2NSF Controller SHOULD implement a mechanism to detect that case. The SDN paradigm generally assumes the I2NSF Controller has a view of the network under its control. This view is built either requesting information to the NSFs under its control, or because these NSFs inform the I2NSF Controller. Based on this information, the I2NSF Controller MAY guess if there is a NAT configured between two hosts, and apply the required policies to both NSFs besides activating the usage of UDP or TCP/TLS encapsulation of ESP packets ([RFC3948], [RFC8229]). The interface for discovering if the NSF is behind a NAT is out of scope of this document.

If the I2NSF Controller does not have any mechanism to know whether a host is behind a NAT or not, then the IKE-case MUST be used and not the IKE-less case.

5.4. NSF registration and discovery

NSF registration refers to the process of facilitating the I2NSF Controller information about a valid NSF such as certificate, IP address, etc. This information is incorporated to a list of NSFs under its control.

The assumption in this document is that, for both cases, before a NSF can operate in this system, it MUST be registered in the I2NSF Controller. In this way, when the NSF starts and establishes a connection to the I2NSF Controller, it knows that the NSF is valid for joining the system.

Either during this registration process or when the NSF connects with the I2NSF Controller, the I2NSF Controller MUST discover certain capabilities of this NSF, such as what is the cryptographic suite supported, authentication method, the support of the IKE case and/or the IKE-less case, etc.

The registration and discovery processes are out of the scope of this document.

6. YANG configuration data models

In order to support the IKE and IKE-less cases we have modeled the different parameters and values that must be configured to manage IPsec SAs. Specifically, the IKE case requires modeling IKEv2 configuration parameters, SPD and PAD, while the IKE-less case requires configuration models for the SPD and SAD. We have defined three models: `ietf-ipsec-common` (Appendix A), `ietf-ipsec-ike` (Appendix B, IKE case), `ietf-ipsec-ikeless` (Appendix C, IKE-less case). Since the model `ietf-ipsec-common` has only typedef and groupings common to the other modules, we only show a simplified view of the `ietf-ipsec-ike` and `ietf-ipsec-ikeless` models.

6.1. IKE case model

The model related to IKEv2 has been extracted from reading IKEv2 standard in [RFC7296], and observing some open source implementations, such as Strongswan [strongswan] or Libreswan [libreswan].

The definition of the PAD model has been extracted from the specification in [section 4.4.3 in \[RFC4301\]](#) (NOTE: We have observed that many implementations integrate PAD configuration as part of the IKEv2 configuration).

```
module: ietf-ipsec-ike
+--rw ipsec-ike
  +--rw pad
    | +--rw pad-entry* [name]
    |   +--rw name                               string
    |   +--rw (identity)
    |     | +--:(ipv4-address)
    |     | | +--rw ipv4-address?                 inet:ipv4-address
    |     | +--:(ipv6-address)
    |     | | +--rw ipv6-address?                 inet:ipv6-address
    |     | +--:(fqdn-string)
    |     | | +--rw fqdn-string?                 inet:domain-name
    |     | +--:(rfc822-address-string)
    |     | | +--rw rfc822-address-string?       string
    |     | +--:(dnx509)
    |     | | +--rw dnx509?                       string
    |     | +--:(gnx509)
    |     | | +--rw gnx509?                       string
    |     | +--:(id-key)
    |     | | +--rw id-key?                       string
    |     | +--:(id-null)
    |     | +--rw id-null?                       empty
```



```

|      +--rw auth-protocol?          auth-protocol-type
|      +--rw peer-authentication
|          +--rw auth-method?        auth-method-type
|          +--rw eap-method
|              | +--rw eap-type      uint8
|          +--rw pre-shared
|              | +--rw secret?       yang:hex-string
|          +--rw digital-signature
|              +--rw ds-algorithm?    uint8
|              +--rw (public-key)
|                  | +--:(raw-public-key)
|                  | | +--rw raw-public-key?  binary
|                  | | +--:(cert-data)
|                  | | +--rw cert-data?      ct:x509
|              +--rw private-key?      binary
|              +--rw ca-data*          ct:x509
|              +--rw crl-data?         ct:crl
|              +--rw crl-uri?         inet:uri
|              +--rw oscp-uri?        inet:uri
+--rw conn-entry* [name]
|   +--rw name                        string
|   +--rw autostartup?               autostartup-type
|   +--rw initial-contact?          boolean
|   +--rw version?                  auth-protocol-type
|   +--rw fragmentation?            boolean
|   +--rw ike-sa-lifetime-soft
|       | +--rw rekey-time?         uint32
|       | +--rw reauth-time?        uint32
|   +--rw ike-sa-lifetime-hard
|       | +--rw over-time?          uint32
|   +--rw authalg*   ic:integrity-algorithm-type
|   +--rw encalg*    ic:encryption-algorithm-type
|   +--rw dh-group?          pfs-group
|   +--rw half-open-ike-sa-timer?    uint32
|   +--rw half-open-ike-sa-cookie-threshold?  uint32
|   +--rw local
|       | +--rw local-pad-entry-name?  string
|   +--rw remote
|       | +--rw remote-pad-entry-name?  string
|   +--rw encapsulation-type
|       | +--rw espencap?    esp-encap
|       | +--rw sport?      inet:port-number
|       | +--rw dport?      inet:port-number
|       | +--rw oaddr*      inet:ip-address
|   +--rw spd
|       | +--rw spd-entry* [name]
|       | | +--rw name      string
|       | | +--rw ipsec-policy-config

```



```

| |      +--rw anti-replay-window?  uint64
| |      +--rw traffic-selector
| |      | +--rw local-subnet        inet:ip-prefix
| |      | +--rw remote-subnet       inet:ip-prefix
| |      | +--rw inner-protocol?     ipsec-inner-protocol
| |      | +--rw local-ports* [start end]
| |      | | +--rw start              inet:port-number
| |      | | +--rw end                inet:port-number
| |      | +--rw remote-ports* [start end]
| |      | | +--rw start              inet:port-number
| |      | | +--rw end                inet:port-number
| |      +--rw processing-info
| |      | +--rw action?              ipsec-spd-action
| |      | +--rw ipsec-sa-cfg
| |      | | +--rw pfp-flag?          boolean
| |      | | +--rw ext-seq-num?       boolean
| |      | | +--rw seq-overflow?      boolean
| |      | | +--rw stateful-frag-check? boolean
| |      | | +--rw mode?              ipsec-mode
| |      | | +--rw protocol-parameters? ipsec-protocol-parameters
| |      | | +--rw esp-algorithms
| |      | | | +--rw integrity*       integrity-algorithm-type
| |      | | | +--rw encryption*     encryption-algorithm-type
| |      | | | +--rw tfc-pad?         boolean
| |      | +--rw tunnel
| |      | | +--rw local              inet:ip-address
| |      | | +--rw remote            inet:ip-address
| |      | | +--rw df-bit?            enumeration
| |      | | +--rw bypass-dscp?       boolean
| |      | | +--rw dscp-mapping?     yang:hex-string
| |      | | +--rw ecn?               boolean
| |      +--rw spd-mark
| |      | +--rw mark?               uint32
| |      | +--rw mask?               yang:hex-string
| +--rw child-sa-info
| | +--rw pfs-groups*                pfs-group
| | +--rw child-sa-lifetime-soft
| | | +--rw time?                    uint32
| | | +--rw bytes?                   uint32
| | | +--rw packets?                 uint32
| | | +--rw idle?                    uint32
| | | +--rw action?                  ic:lifetime-action
| | +--rw child-sa-lifetime-hard
| | | +--rw time?                    uint32
| | | +--rw bytes?                   uint32
| | | +--rw packets?                 uint32
| | | +--rw idle?                    uint32
| +--ro state

```



```

|    +--ro initiator?                boolean
|    +--ro initiator-ikesa-spi?     ike-spi
|    +--ro responder-ikesa-spi?     ike-spi
|    +--ro nat-local?               boolean
|    +--ro nat-remote?              boolean
|    +--ro encapsulation-type
|    |    +--ro espencap?            esp-encap
|    |    +--ro sport?              inet:port-number
|    |    +--ro dport?              inet:port-number
|    |    +--ro oaddr*              inet:ip-address
|    +--ro established?             uint64
|    +--ro current-rekey-time?       uint64
|    +--ro current-reauth-time?      uint64
+--ro number-ike-sas
    +--ro total?                    uint64
    +--ro half-open?                uint64
    +--ro half-open-cookies?         uint64

```

[Appendix D](#) shows an example of IKE case configuration for a NSF, in tunnel mode (gateway-to-gateway), with NSFs authentication based on X.509 certificates.

6.2. IKE-less case model

For this case, the definition of the SPD model has been mainly extracted from the specification in [section 4.4.1](#) and [Appendix D in \[RFC4301\]](#), though with some changes, namely:

- o Each IPsec policy (spd-entry) contains one traffic selector, instead of a list of them. The reason is that we have observed actual kernel implementations only admit a single traffic selector per IPsec policy.
- o Each IPsec policy contains a identifier (reqid) to relate the policy with the IPsec SA. This is common in Linux-based systems.
- o Each IPsec policy has only one name and not a list of names.
- o Combined algorithms has been removed because encryption algorithms MAY include authenticated encryption with associated data (AEAD).
- o Tunnel information has been extended with information about DSCP mapping and ECN bit. The reason is that we have observed real kernel implementations admit the configurations of these values.

The definition of the SAD model has been mainly extracted from the specification in [section 4.4.2 in \[RFC4301\]](#) though with some changes, namely:

- o Each IPsec SA (sad-entry) contains one traffic selector, instead of a list of them. The reason is that we have observed actual kernel implementations only admit a single traffic selector per IPsec SA.
- o Each IPsec SA contains a identifier (reqid) to relate the policy with the IPsec Policy. The reason is that we have observed real kernel implementations allow to include this value.
- o Each IPsec SA has also a name in the same way as IPsec policies.
- o Combined algorithm has been removed because encryption algorithm MAY include authenticated encryption with associated data (AEAD).
- o Tunnel information has been extended with information about Differentiated Services Code Point (DSCP) mapping and Explicit Congestion Notifiction (ECN) bit. The reason is that we have observed actual kernel implementations admit the configurations of these values.
- o Lifetime of the IPsec SAs also include idle time and number of IP packets as threshold to trigger the lifetime. The reason is that we have observed actual kernel implementations allow to set these types of lifetimes.
- o Information to configure the type of encapsulation (encapsulation-type) for IPsec ESP packets in UDP ([\[RFC3948\]](#)), TCP ([\[RFC8229\]](#)) or TLS ([\[RFC8229\]](#)) has been included.

The notifications model has been defined using as reference the PF_KEYv2 standard in [\[RFC2367\]](#).

```
module: ietf-ipsec-ikeless
+--rw ipsec-ikeless
+--rw spd
|   +--rw spd-entry* [name]
|       +--rw name                string
|       +--rw direction?          ic:ipsec-traffic-direction
|       +--rw reqid?              uint64
|       +--rw ipsec-policy-config
|           +--rw anti-replay-window?  uint64
|           +--rw traffic-selector
|               | +--rw local-subnet    inet:ip-prefix
```



```

|         | +--rw remote-subnet      inet:ip-prefix
|         | +--rw inner-protocol?    ipsec-inner-protocol
|         | +--rw local-ports* [start end]
|         | | +--rw start            inet:port-number
|         | | +--rw end              inet:port-number
|         | +--rw remote-ports* [start end]
|         |   +--rw start            inet:port-number
|         |   +--rw end              inet:port-number
| +--rw processing-info
|         | +--rw action?            ipsec-spd-action
|         | +--rw ipsec-sa-cfg
|         |   +--rw pfp-flag?        boolean
|         |   +--rw ext-seq-num?     boolean
|         |   +--rw seq-overflow?    boolean
|         |   +--rw stateful-frag-check? boolean
|         |   +--rw mode?            ipsec-mode
|         |   +--rw protocol-parameters?
|         |   +--rw esp-algorithms
|         |     | +--rw integrity*    integrity-algorithm-type
|         |     | +--rw encryption*  encryption-algorithm-type
|         |     | +--rw tfc-pad?     boolean
|         |   +--rw tunnel
|         |     +--rw local          inet:ip-address
|         |     +--rw remote        inet:ip-address
|         |     +--rw df-bit?       enumeration
|         |     +--rw bypass-dscp?  boolean
|         |     +--rw dscp-mapping? yang:hex-string
|         |     +--rw ecn?          boolean
| +--rw spd-mark
|         +--rw mark?    uint32
|         +--rw mask?    yang:hex-string
+--rw sad
+--rw sad-entry* [name]
  +--rw name          string
  +--rw reqid?        uint64
  +--rw ipsec-sa-config
    | +--rw spi          uint32
    | +--rw ext-seq-num? boolean
    | +--rw seq-number-counter? uint64
    | +--rw seq-overflow? boolean
    | +--rw anti-replay-window? uint32
    | +--rw traffic-selector
    | | +--rw local-subnet    inet:ip-prefix
    | | +--rw remote-subnet   inet:ip-prefix
    | | +--rw inner-protocol? ipsec-inner-protocol
    | | +--rw local-ports*    [start end]
    | | | +--rw start        inet:port-number
    | | | +--rw end          inet:port-number

```



```
| | +--rw remote-ports* [start end]
| |   +--rw start          inet:port-number
| |   +--rw end            inet:port-number
| +--rw protocol-parameters? ic:ipsec-protocol-parameters
| +--rw mode?              ic:ipsec-mode
| +--rw esp-sa
| |   +--rw encryption
| | |   +--rw encryption-algorithm? ic:encryption-algorithm-type
| | |   +--rw key?                yang:hex-string
| | |   +--rw iv?                 yang:hex-string
| |   +--rw integrity
| | |   +--rw integrity-algorithm? ic:integrity-algorithm-type
| | |   +--rw key?                yang:hex-string
| +--rw sa-lifetime-hard
| |   +--rw time?      uint32
| |   +--rw bytes?    uint32
| |   +--rw packets?  uint32
| |   +--rw idle?     uint32
| +--rw sa-lifetime-soft
| |   +--rw time?      uint32
| |   +--rw bytes?    uint32
| |   +--rw packets?  uint32
| |   +--rw idle?     uint32
| |   +--rw action?    ic:lifetime-action
| +--rw tunnel
| |   +--rw local      inet:ip-address
| |   +--rw remote     inet:ip-address
| |   +--rw df-bit?    enumeration
| |   +--rw bypass-dscp? boolean
| |   +--rw dscp-mapping? yang:hex-string
| |   +--rw ecn?       boolean
| +--rw encapsulation-type
| |   +--rw espencap?  esp-encap
| |   +--rw sport?    inet:port-number
| |   +--rw dport?    inet:port-number
| |   +--rw oaddr*    inet:ip-address
+--ro ipsec-sa-state
  +--ro sa-lifetime-current
    | +--ro time?      uint32
    | +--ro bytes?    uint32
    | +--ro packets?  uint32
    | +--ro idle?     uint32
  +--ro replay-stats
    +--ro replay-window?      uint64
    +--ro packet-dropped?     uint64
    +--ro failed?             uint32
    +--ro seq-number-counter? uint64
```



```

notifications:
+---n sadb-acquire
| +--ro ipsec-policy-name      string
| +--ro traffic-selector
|   +--ro local-subnet        inet:ip-prefix
|   +--ro remote-subnet       inet:ip-prefix
|   +--ro inner-protocol?     ipsec-inner-protocol
|   +--ro local-ports* [start end]
|     | +--ro start            inet:port-number
|     | +--ro end              inet:port-number
|   +--ro remote-ports* [start end]
|     +--ro start              inet:port-number
|     +--ro end                inet:port-number
+---n sadb-expire
| +--ro ipsec-sa-name          string
| +--ro soft-lifetime-expire?  boolean
| +--ro lifetime-current
|   +--ro time?                uint32
|   +--ro bytes?               uint32
|   +--ro packets?             uint32
|   +--ro idle?                uint32
+---n sadb-seq-overflow
| +--ro ipsec-sa-name          string
+---n sadb-bad-spi
| +--ro spi                    uint32

```

[Appendix E](#) shows an example of IKE-less case configuration for a NSF, in transport mode (host-to-host), with NSFs authentication based on shared secrets. For the IKE-less case, [Appendix F](#) shows examples of IPsec SA expire, acquire, sequence number overflow and bad SPI notifications.

7. IANA Considerations

This document registers three URIs in the "ns" subregistry of the IETF XML Registry [[RFC3688](#)]. Following the format in [[RFC3688](#)], the following registrations are requested:

URI: urn:ietf:params:xml:ns:yang:ietf-ipsec-common
Registrant Contact: The I2NSF WG of the IETF.
XML: N/A, the requested URI is an XML namespace.

URI: urn:ietf:params:xml:ns:yang:ietf-ipsec-ike
Registrant Contact: The I2NSF WG of the IETF.
XML: N/A, the requested URI is an XML namespace.

URI: urn:ietf:params:xml:ns:yang:ietf-ipsec-ikeless
Registrant Contact: The I2NSF WG of the IETF.
XML: N/A, the requested URI is an XML namespace.

This document registers three YANG modules in the "YANG Module Names" registry [[RFC6020](#)]. Following the format in [[RFC6020](#)], the following registrations are requested:

Name: ietf-ipsec-common
Namespace: urn:ietf:params:xml:ns:yang:ietf-ipsec-common
Prefix: ic
Reference: RFC XXXX

Name: ietf-ipsec-ike
Namespace: urn:ietf:params:xml:ns:yang:ietf-ipsec-ike
Prefix: ike
Reference: RFC XXXX

Name: ietf-ipsec-ikeless
Namespace: urn:ietf:params:xml:ns:yang:ietf-ipsec-ikeless
Prefix: ikeless
Reference: RFC XXXX

8. Security Considerations

First of all, this document shares all the security issues of SDN that are specified in the "Security Considerations" section of [[ITU-T.Y.3300](#)] and [[RFC7426](#)].

On the one hand, it is important to note that there MUST exist a security association between the I2NSF Controller and the NSFs to protect the critical information (cryptographic keys, configuration parameter, etc.) exchanged between these entities.

On the other hand, if encryption is mandatory for all traffic of a NSF, its default policy MUST be to drop (DISCARD) packets to prevent cleartext packet leaks. This default policy MUST be pre-configured in the startup configuration datastore in the NSF before the NSF contacts the I2NSF Controller. Moreover, the startup configuration datastore MUST be also pre-configured with the required ALLOW

policies that allow to communicate the NSF with the I2NSF Controller once the NSF is deployed. This pre-configuration step is not carried out by the I2NSF Controller but by some other entity before the NSF deployment. In this manner, when the NSF starts/reboots, it will always first apply the configuration in the startup configuration before contacting the I2NSF Controller.

Finally, we have divided this section in two parts in order to analyze different security considerations for both cases: NSF with IKEv2 (IKE case) and NSF without IKEv2 (IKE-less case). In general, the I2NSF Controller, as typically in the SDN paradigm, is a target for different type of attacks [[SDNSecServ](#)] and [[SDNSecurity](#)]. Thus, the I2NSF Controller is a key entity in the infrastructure and MUST be protected accordingly. In particular, the I2NSF Controller will handle cryptographic material so that the attacker may try to access this information. Although we can assume this attack will not likely to happen due to the assumed security measurements to protect the I2NSF Controller, it deserves some analysis in the hypothetical case the attack occurs. The impact is different depending on the IKE case or IKE-less case.

8.1. IKE case

In the IKE case, the I2NSF Controller sends IKEv2 credentials (PSK, public/private keys, certificates, etc.) to the NSFs using the security association between I2NSF Controller and NSFs. The I2NSF Controller MUST NOT store the IKEv2 credentials after distributing them. Moreover, the NSFs MUST NOT allow the reading of these values once they have been applied by the I2NSF Controller (i.e. write only operations). One option is to always return the same value (i.e. all 0s) if a read operation is carried out.

If the attacker has access to the I2NSF Controller during the period of time that key material is generated, it might have access to the key material. Since these values are used during NSF authentication in IKEv2, it may impersonate the affected NSFs. Several recommendations are important.

- o IKEv2 configurations should adhere to the recommendations in [[RFC8247](#)].
- o If PSK authentication is used in IKEv2, the I2NSF Controller MUST remove the PSK immediately after generating and distributing it.
- o When public/private keys are used, the I2NSF Controller MAY generate both public key and private key. In such a case, the I2NSF Controller MUST remove the associated private key immediately after distributing them to the NSFs. Alternatively,

the NSF could generate the private key and export only the public key to the I2NSF Controller.

- o If certificates are used, the NSF MAY generate the private key and exports the public key for certification to the I2NSF Controller. How the NSF generates these cryptographic material (public key/private keys) and exports the public key it is out of scope of this document.

8.2. IKE-less case

In the IKE-less case, the I2NSF Controller sends the IPsec SA information to the NSF's SAD that includes the private session keys required for integrity and encryption. The I2NSF Controller MUST NOT store the keys after distributing them. Moreover, the NSFs receiving private key material MUST NOT allow the reading of these values by any other entity (including the I2NSF Controller itself) once they have been applied (i.e. write only operations) into the NSFs. Nevertheless, if the attacker has access to the I2NSF Controller during the period of time that key material is generated, it may obtain these values. In other words, the attacker might be able to observe the IPsec traffic and decrypt, or even modify and re-encrypt, the traffic between peers.

8.3. YANG modules

The YANG module specified in this document defines a schema for data that is designed to be accessed via network management protocols such as NETCONF [[RFC6241](#)] or RESTCONF [[RFC8040](#)]. The lowest NETCONF layer is the secure transport layer, and the mandatory-to-implement secure transport is Secure Shell (SSH) [[RFC6242](#)]. The lowest RESTCONF layer is HTTPS, and the mandatory-to-implement secure transport is TLS [[RFC8446](#)].

The Network Configuration Access Control Model (NACM) [[RFC8341](#)] provides the means to restrict access for particular NETCONF or RESTCONF users to a preconfigured subset of all available NETCONF or RESTCONF protocol operations and content.

There are a number of data nodes defined in these YANG modules that are writable/creatable/deletable (i.e., config true, which is the default). These data nodes may be considered sensitive or vulnerable in some network environments. Write operations (e.g., edit-config) to these data nodes without proper protection can have a negative effect on network operations. These are the subtrees and data nodes and their sensitivity/vulnerability:

The YANG modules describe configuration data for the IKE case (`ietf-ipsec-ike`) and IKE-less case (`ietf-ipsec-ikeless`). There is a common module (`ietf-ipsec-common`) used in both cases.

For the IKE case (`ietf-ipsec-ike`):

`/ipsec-ike`: The entire container in this module is sensitive to write operations. An attacker may add/modify the credentials to be used for the authentication (e.g. to impersonate a NSF), the trust root (e.g. changing the trusted CA certificates), the cryptographic algorithms (allowing a downgrading attack), the IPsec policies (e.g. by allowing leaking of data traffic by changing to a allow policy), and in general changing the IKE SA conditions and credentials between any NSF.

For the IKE-less case (`ietf-ipsec-ikeless`):

`/ipsec-ikeless`: The entire container in this module is sensitive to write operations. An attacker may add/modify/delete any IPsec policies (e.g. by allowing leaking of data traffic by changing to a allow policy) in the `/ipsec-ikeless/spd` container, and add/modify/delete any IPsec SAs between two NSF by means of `/ipsec-ikeless/sad` container and, in general changing any IPsec SAs and IPsec policies between any NSF.

Some of the readable data nodes in this YANG module may be considered sensitive or vulnerable in some network environments. It is thus important to control read access (e.g., via `get`, `get-config`, or `notification`) to these data nodes. These are the subtrees and data nodes and their sensitivity/vulnerability:

For the IKE case (`ietf-ipsec-ike`):

`/ipsec-ike/pad`: This container includes sensitive information to read operations. This information should never be returned to a client. For example, cryptographic material configured in the NSFs: `peer-authentication/pre-shared/secret` and `peer-authentication/digital-signature/private-key` are already protected by the NACM extension "default-deny-all" in this document.

For the IKE-less case (`ietf-ipsec-ikeless`):

`/ipsec-ikeless/sad/ipsec-sa-config/esp-sa`: This container includes symmetric keys for the IPsec SAs. For example, `encryption/key` contains a ESP encryption key value and `encryption/iv` contains a initialization vector value. Similarly, `integrity/key` has ESP integrity key value. Those

values must not be read by anyone and are protected by the NACM extension "default-deny-all" in this document.

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Appendix A. Common YANG model for IKE and IKE-less cases

```
<CODE BEGINS> file "ietf-ipsec-common@2019-08-05.yang"

module ietf-ipsec-common {
  yang-version 1.1;
  namespace "urn:ietf:params:xml:ns:yang:ietf-ipsec-common";
  prefix "ipsec-common";

  import ietf-inet-types { prefix inet; }
  import ietf-yang-types { prefix yang; }

  organization "IETF I2NSF Working Group";

  contact
    "WG Web: <https://datatracker.ietf.org/wg/i2nsf/about/>
    WG List: <mailto:i2nsf@ietf.org>

    Author: Rafael Marin-Lopez
            <mailto:rafa@um.es>

    Author: Gabriel Lopez-Millan
            <mailto:gabilm@um.es>

    Author: Fernando Pereniguez-Garcia
            <mailto:fernando.pereniguez@tud.upct.es>

  ";

  description
    "Common Data model for the IKE and IKE-less cases
    defined by the SDN-based IPsec flow protection service.

    Copyright (c) 2019 IETF Trust and the persons
    identified as authors of the code. All rights reserved.
    Redistribution and use in source and binary forms, with
    or without modification, is permitted pursuant to, and
    subject to the license terms contained in, the
    Simplified BSD License set forth in Section 4.c of the
    IETF Trust's Legal Provisions Relating to IETF Documents
    (https://trustee.ietf.org/license-info).

    This version of this YANG module is part of RFC XXXX;;
    see the RFC itself for full legal notices.

    The key words 'MUST', 'MUST NOT', 'REQUIRED', 'SHALL',
    'SHALL NOT', 'SHOULD', 'SHOULD NOT', 'RECOMMENDED',
```


'NOT RECOMMENDED', 'MAY', and 'OPTIONAL' in this document are to be interpreted as described in [BCP 14](#) ([RFC 2119](#)) ([RFC 8174](#)) when, and only when, they appear in all capitals, as shown here.";

```
revision "2019-08-05" {
  description "Revision 06";
  reference "RFC XXXX: YANG Groupings and typedef
            for IKE and IKE-less case";
}

typedef encryption-algorithm-type {
  type uint16;
  description
    "The encryption algorithm is specified with a 16-bit
     number extracted from IANA Registry. The acceptable
     values MUST follow the requirement levels for
     encryption algorithms for ESP and IKEv2.";
  reference
    "IANA Registry- Transform Type 1 - Encryption
     Algorithm Transform IDs. RFC 8221 - Cryptographic
     Algorithm Implementation Requirements and Usage
     Guidance for Encapsulating Security Payload (ESP)
     and Authentication Header (AH) and RFC 8247 -
     Algorithm Implementation Requirements and Usage
     Guidance for the Internet Key Exchange Protocol
     Version 2 (IKEv2).";
}

typedef integrity-algorithm-type {
  type uint16;
  description
    "The integrity algorithm is specified with a 16-bit
     number extracted from IANA Registry.
     The acceptable values MUST follow the requirement
     levels for encryption algorithms for ESP and IKEv2.";
  reference
    "IANA Registry- Transform Type 3 - Integrity
     Algorithm Transform IDs. RFC 8221 - Cryptographic
     Algorithm Implementation Requirements and Usage
     Guidance for Encapsulating Security Payload (ESP)
     and Authentication Header (AH) and RFC 8247 -
     Algorithm Implementation Requirements and Usage
     Guidance for the Internet Key Exchange Protocol
     Version 2 (IKEv2).";
}

typedef ipsec-mode {
```



```
    type enumeration {
        enum transport {
            description
                "IPsec transport mode. No Network Address
                Translation (NAT) support.";
        }
        enum tunnel {
            description "IPsec tunnel mode.";
        }
    }
    description
        "Type definition of IPsec mode: transport or
        tunnel.";
    reference
        "Section 3.2 in RFC 4301.";
}

typedef esp-encap {
    type enumeration {
        enum espintcp {
            description
                "ESP in TCP encapsulation.";
            reference
                "RFC 8229 - TCP Encapsulation of IKE and
                IPsec Packets.";
        }
        enum espintls {
            description
                "ESP in TCP encapsulation using TLS.";
            reference
                "RFC 8229 - TCP Encapsulation of IKE and
                IPsec Packets.";
        }
        enum espinudp {
            description
                "ESP in UDP encapsulation.";
            reference
                "RFC 3948 - UDP Encapsulation of IPsec ESP
                Packets.";
        }
        enum none {
            description
                "NOT ESP encapsulation.";
        }
    }
}
description
    "Types of ESP encapsulation when Network Address
    Translation (NAT) is present between two NSFs.";
```



```
reference
    "RFC 8229 - TCP Encapsulation of IKE and IPsec
    Packets and RFC 3948 - UDP Encapsulation of IPsec
    ESP Packets.";
}

typedef ipsec-protocol-parameters {
    type enumeration {
        enum esp { description "IPsec ESP protocol."; }
    }
    description
        "Only the Encapsulation Security Protocol (ESP) is
        supported but it could be extended in the future.";
    reference
        "RFC 4303- IP Encapsulating Security Payload
        (ESP).";
}

typedef lifetime-action {
    type enumeration {
        enum terminate-clear {
            description
                "Terminates the IPsec SA and allows the
                packets through.";
        }
        enum terminate-hold {
            description
                "Terminates the IPsec SA and drops the
                packets.";
        }
        enum replace {
            description
                "Replaces the IPsec SA with a new one:
                rekey. ";
        }
    }
    description
        "When the lifetime of an IPsec SA expires an action
        needs to be performed over the IPsec SA that
        reached the lifetime. There are three possible
        options: terminate-clear, terminate-hold and
        replace.";
    reference
        "Section 4.5 in RFC 4301.";
}

typedef ipsec-traffic-direction {
```



```
    type enumeration {
        enum inbound {
            description "Inbound traffic.";
        }
        enum outbound {
            description "Outbound traffic.";
        }
    }
    description
        "IPsec traffic direction is defined in two
        directions: inbound and outbound. From a NSF
        perspective inbound means the traffic that enters
        the NSF and outbound is the traffic that is sent
        from the NSF.";
    reference
        "Section 5 in RFC 4301.";
}

typedef ipsec-spdl-action {
    type enumeration {
        enum protect {
            description
                "PROTECT the traffic with IPsec.";
        }
        enum bypass {
            description
                "BYPASS the traffic. The packet is forwarded
                without IPsec protection.";
        }
        enum discard {
            description
                "DISCARD the traffic. The IP packet is
                discarded.";
        }
    }
    description
        "The action when traffic matches an IPsec security
        policy. According to RFC 4301 there are three
        possible values: BYPASS, PROTECT AND DISCARD";
    reference
        "Section 4.4.1 in RFC 4301.";
}

typedef ipsec-inner-protocol {
    type union {
        type uint8;
        type enumeration {
            enum any {
```



```
        value 256;
        description
            "Any IP protocol number value.";
    }
}
default any;
description
    "IPsec protection can be applied to specific IP
    traffic and layer 4 traffic (TCP, UDP, SCTP, etc.)
    or ANY protocol in the IP packet payload. We
    specify the IP protocol number with an uint8 or
    ANY defining an enumerate with value 256 to
    indicate the protocol number.";
reference
    "Section 4.4.1.1 in RFC 4301.
    IANA Registry - Protocol Numbers.";
}

grouping encap {
    description
        "This group of nodes allows to define the type of
        encapsulation in case NAT traversal is
        required and port information.";
    leaf espencap {
        type esp-encap;
        description
            "ESP in TCP, ESP in UDP or ESP in TLS.";
    }
    leaf sport {
        type inet:port-number;
        default 4500;
        description
            "Encapsulation source port.";
    }
    leaf dport {
        type inet:port-number;
        default 4500;
        description
            "Encapsulation destination port.";
    }
}

leaf-list oaddr {
    type inet:ip-address;
    description
        "If required, this is the original address that
        was used before NAT was applied over the Packet.
        ";
}
```



```
    }
    reference
        "RFC 3947 and RFC 8229.";
}

grouping lifetime {
    description
        "Different lifetime values limited to an IPsec SA.";
    leaf time {
        type uint32;
        default 0;
        description
            "Time in seconds since the IPsec SA was added.
             For example, if this value is 180 seconds it
             means the IPsec SA expires in 180 seconds since
             it was added. The value 0 implies infinite.";
    }
    leaf bytes {
        type uint32;
        default 0;
        description
            "If the IPsec SA processes the number of bytes
             expressed in this leaf, the IPsec SA expires and
             should be rekeyed. The value 0 implies
             infinite.";
    }
    leaf packets {
        type uint32;
        default 0;
        description
            "If the IPsec SA processes the number of packets
             expressed in this leaf, the IPsec SA expires and
             should be rekeyed. The value 0 implies
             infinite.";
    }
    leaf idle {
        type uint32;
        default 0;
        description
            "When a NSF stores an IPsec SA, it
             consumes system resources. In an idle NSF this
             is a waste of resources. If the IPsec SA is idle
             during this number of seconds the IPsec SA
             should be removed. The value 0 implies
             infinite.";
    }
    reference
        "Section 4.4.2.1 in RFC 4301.";
}
```



```
}

grouping port-range {
  description
    "This grouping defines a port range, such as
    expressed in RFC 4301. For example: 1500 (Start
    Port Number)-1600 (End Port Number). A port range
    is used in the Traffic Selector.";

  leaf start {
    type inet:port-number;
    description
      "Start port number.";
  }
  leaf end {
    type inet:port-number;
    description
      "End port number.";
  }
  reference "Section 4.4.1.2 in RFC 4301";
}

grouping tunnel-grouping {
  description
    "The parameters required to define the IP tunnel
    endpoints when IPsec SA requires tunnel mode. The
    tunnel is defined by two endpoints: the local IP
    address and the remote IP address.";

  leaf local {
    type inet:ip-address;
    mandatory true;
    description
      "Local IP address' tunnel endpoint.";
  }
  leaf remote {
    type inet:ip-address;
    mandatory true;
    description
      "Remote IP address' tunnel endpoint.";
  }
  leaf df-bit {
    type enumeration {
      enum clear {
        description
          "Disable the DF (Don't Fragment) bit
          from the outer header. This is the
          default value.";
      }
    }
  }
}
```



```
    }
    enum set {
        description
            "Enable the DF bit in the outer header.";
    }
    enum copy {
        description
            "Copy the DF bit to the outer header.";
    }
}
default clear;
description
    "Allow configuring the DF bit when encapsulating
    tunnel mode IPsec traffic. RFC 4301 describes
    three options to handle the DF bit during
    tunnel encapsulation: clear, set and copy from
    the inner IP header.";
reference
    "Section 8.1 in RFC 4301.";
}
leaf bypass-dscp {
    type boolean;
    default true;
    description
        "If DSCP (Differentiated Services Code Point)
        values in the inner header have to be used to
        select one IPsec SA among several that match
        the traffic selectors for an outbound packet";
    reference
        "Section 4.4.2.1. in RFC 4301.";
}
leaf dscp-mapping {
    type yang:hex-string;
    description
        "DSCP values allowed for packets carried over
        this IPsec SA.";
    reference
        "Section 4.4.2.1. in RFC 4301.";
}
leaf ecn {
    type boolean;
    default false;
    description
        "Explicit Congestion Notification (ECN). If true
        copy CE bits to inner header.";
    reference
        "Section 5.1.2 and Annex C in RFC 4301.";
}
```



```
}

grouping selector-grouping {
  description
    "This grouping contains the definition of a Traffic
    Selector, which is used in the IPsec policies and
    IPsec SAs.";

  leaf local-subnet {
    type inet:ip-prefix;
    mandatory true;
    description
      "Local IP address subnet.";
  }
  leaf remote-subnet {
    type inet:ip-prefix;
    mandatory true;
    description
      "Remote IP address subnet.";
  }
  leaf inner-protocol {
    type ipsec-inner-protocol;
    default any;
    description
      "Inner Protocol that is going to be
      protected with IPsec.";
  }
  list local-ports {
    key "start end";
    uses port-range;
    description
      "List of local ports. When the inner
      protocol is ICMP this 16 bit value represents
      code and type.";
  }
  list remote-ports {
    key "start end";
    uses port-range;
    description
      "List of remote ports. When the upper layer
      protocol is ICMP this 16 bit value represents
      code and type.";
  }
  reference
    "Section 4.4.1.2 in RFC 4301";
}

grouping ipsec-policy-grouping {
```



```
description
    "Holds configuration information for an IPsec SPD
    entry.";

leaf anti-replay-window {
    type uint64;
    default 32;
    description
        "A 64-bit counter used to determine whether an
        inbound ESP packet is a replay.";
    reference
        "Section 4.4.2.1 in RFC 4301.";
}
container traffic-selector {
    description
        "Packets are selected for
        processing actions based on the IP and inner
        protocol header information, selectors,
        matched against entries in the SPD.";
    uses selector-grouping;
    reference
        "Section 4.4.4.1 in RFC 4301.";
}
container processing-info {
    description
        "SPD processing. If the required processing
        action is protect, it contains the required
        information to process the packet.";
    leaf action {
        type ipsec-spd-action;
        default discard;
        description
            "If bypass or discard, container
            ipsec-sa-cfg is empty.";
    }
    container ipsec-sa-cfg {
        when "../action = 'protect'";
        description
            "IPsec SA configuration included in the SPD
            entry.";
        leaf pfp-flag {
            type boolean;
            default false;
            description
                "Each selector has a Populate From
                Packet (PFP) flag. If asserted for a
                given selector X, the flag indicates
                that the IPsec SA to be created should
```



```
        take its value (local IP address,
        remote IP address, Next Layer
        Protocol, etc.) for X from the value
        in the packet. Otherwise, the IPsec SA
        should take its value(s) for X from
        the value(s) in the SPD entry.";
    }
    leaf ext-seq-num {
        type boolean;
        default false;
        description
            "True if this IPsec SA is using extended
            sequence numbers. True 64 bit counter,
            False 32 bit.";
    }
    leaf seq-overflow {
        type boolean;
        default false;
        description
            "The flag indicating whether
            overflow of the sequence number
            counter should prevent transmission
            of additional packets on the IPsec
            SA (false) and, therefore needs to
            be rekeyed, or whether rollover is
            permitted (true). If Authenticated
            Encryption with Associated Data
            (AEAD) is used this flag MUST be
            false.";
    }
    leaf stateful-frag-check {
        type boolean;
        default false;
        description
            "Indicates whether (true) or not (false)
            stateful fragment checking applies to
            the IPsec SA to be created.";
    }
    leaf mode {
        type ipsec-mode;
        default transport;
        description
            "IPsec SA has to be processed in
            transport or tunnel mode.";
    }
    leaf protocol-parameters {
        type ipsec-protocol-parameters;
        default esp;
    }
}
```



```
        description
            "Security protocol of the IPsec SA:
            Only ESP is supported but it could be
            extended in the future.";
    }
    container esp-algorithms {
        when "../protocol-parameters = 'esp'";
        description
            "Configuration of Encapsulating
            Security Payload (ESP) parameters and
            algorithms.";
        leaf-list integrity {
            type integrity-algorithm-type;
            default 0;
            ordered-by user;
            description
                "Configuration of ESP authentication
                based on the specified integrity
                algorithm. With AEAD algorithms,
                the integrity node is not
                used.";
            reference
                "Section 3.2 in RFC 4303";
        }
        leaf-list encryption {
            type encryption-algorithm-type;
            default 20;
            ordered-by user;
            description
                "Configuration of ESP encryption
                algorithms. The default value is
                20 (ENCR_AES_GCM_16).";
            reference
                "Section 3.2 in RFC 4303";
        }
        leaf tfc-pad {
            type boolean;
            default false;
            description
                "If Traffic Flow Confidentiality
                (TFC) padding for ESP encryption
                can be used (true) or not (false)";
            reference
                "Section 2.7 in RFC 4303";
        }
        reference
            "RFC 4303";
    }
}
```



```
        container tunnel {
            when "../mode = 'tunnel'";
            uses tunnel-grouping;
            description
                "IPsec tunnel endpoints definition.";
        }
    }
    reference
        "Section 4.4.1.2 in RFC 4301";
}
container spd-mark {
    description
        "The Mark to set for the IPsec SA of this
        connection. This option is only available
        on linux NETKEY/XFRM kernels. It can be
        used with iptables to create custom
        iptables rules using CONNMARK. It can also
        be used with Virtual Tunnel Interfaces
        (VTI) to direct marked traffic to
        specific vtixX devices.";
    leaf mark {
        type uint32;
        default 0;
        description
            "Mark used to match XFRM policies and
            states.";
    }
    leaf mask {
        type yang:hex-string;
        default 00:00:00:00;
        description
            "Mask used to match XFRM policies and
            states.";
    }
}
}
}
}
<CODE ENDS>
```

[Appendix B](#). YANG model for IKE case

<CODE BEGINS> file "ietf-ipsec-ike@2019-08-05.yang"


```
module ietf-ipsec-ike {
  yang-version 1.1;
  namespace "urn:ietf:params:xml:ns:yang:ietf-ipsec-ike";
  prefix "ike";

  import ietf-inet-types { prefix inet; }
  import ietf-yang-types { prefix yang; }

  import ietf-crypto-types {
    prefix ct;
    reference
      "draft-ietf-netconf-crypto-types-10:
      Common YANG Data Types for Cryptography.";
  }

  import ietf-ipsec-common {
    prefix ic;
    reference
      "RFC XXXX: module ietf-ipsec-common, revision
      2019-08-05.";
  }

  import ietf-netconf-acm {
    prefix nacm;
    reference
      "RFC 8341: Network Configuration Access Control
      Model.";
  }

  organization "IETF I2NSF Working Group";

  contact
    "WG Web:  <https://datatracker.ietf.org/wg/i2nsf/about/>
    WG List: <mailto:i2nsf@ietf.org>

    Author: Rafael Marin-Lopez
           <mailto:rafa@um.es>

    Author: Gabriel Lopez-Millan
           <mailto:gabilm@um.es>

    Author: Fernando Pereniguez-Garcia
           <mailto:fernando.pereniguez@ud.upct.es>
  ";

  description
    "This module contains IPsec IKE case model for the SDN-based
```


IPsec flow protection service. An NSF will implement this module.

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This version of this YANG module is part of RFC XXXX; see the RFC itself for full legal notices.

The key words 'MUST', 'MUST NOT', 'REQUIRED', 'SHALL', 'SHALL NOT', 'SHOULD', 'SHOULD NOT', 'RECOMMENDED', 'NOT RECOMMENDED', 'MAY', and 'OPTIONAL' in this document are to be interpreted as described in [BCP 14](#) ([RFC 2119](#)) ([RFC 8174](#)) when, and only when, they appear in all capitals, as shown here.";

```
revision "2019-08-05" {
    description "Revision 6";
    reference
        "RFC XXXX: YANG model for IKE case.";
}

typedef ike-spi {
    type uint64 { range "0..max"; }
    description
        "Security Parameter Index (SPI)'s IKE SA.";
    reference
        "Section 2.6 in RFC 7296.";
}

typedef autostartup-type {
    type enumeration {
        enum add {
            description
                "IKE/IPsec configuration is only loaded into
                 IKE implementation but IKE/IPsec SA is not
                 started.";
        }
        enum on-demand {
            description
```



```
        "IKE/IPsec configuration is loaded
        into IKE implementation. The IPsec policies
        are transferred to the NSF's kernel but the
        IPsec SAs are not established immediately.
        The IKE implementation will negotiate the
        IPsec SAs when the NSF's kernel requests it
        (i.e. through an ACQUIRE notification).";
    }
    enum start {
        description "IKE/IPsec configuration is loaded
        and transferred to the NSF's kernel, and the
        IKEv2 based IPsec SAs are established
        immediately without waiting any packet.";
    }
}
description
    "Different policies to set IPsec SA configuration
    into NSF's kernel when IKEv2 implementation has
    started.";
}

typedef pfs-group {
    type uint16;
    description
        "DH groups for IKE and IPsec SA rekey.";
    reference
        "Section 3.3.2 in RFC 7296. Transform Type 4 -
        Diffie-Hellman Group Transform IDs in IANA Registry
        - Internet Key Exchange Version 2 (IKEv2)
        Parameters.";
}

typedef auth-protocol-type {
    type enumeration {
        enum ikev2 {
            value 2;
            description
                "IKEv2 authentication protocol. It is the
                only defined right now. An enum is used for
                further extensibility.";
        }
    }
}
description
    "IKE authentication protocol version specified in the
    Peer Authorization Database (PAD). It is defined as
    enumerate to allow new IKE versions in the
```



```
        future.";
    reference
        "RFC 7296.";
}

typedef auth-method-type {
    type enumeration {
        enum pre-shared {
            description
                "Select pre-shared key as the
                authentication method.";
            reference
                "RFC 7296.";
        }
        enum eap {
            description
                "Select EAP as the authentication method.";
            reference
                "RFC 7296.";
        }
        enum digital-signature {
            description
                "Select digital signature method.";
            reference
                "RFC 7296 and RFC 7427.";
        }
        enum null {
            description
                "Null authentication.";
            reference
                "RFC 7619.";
        }
    }
    description
        "Peer authentication method specified in the Peer
        Authorization Database (PAD).";
}

container ipsec-ike {
    description
        "IKE configuration for a NSF. It includes PAD
        parameters, IKE connections information and state
        data.";

    container pad {
        description
            "Configuration of Peer Authorization Database
```


(PAD). The PAD contains information about IKE peer (local and remote). Therefore, the Security Controller also stores authentication information for this NSF and can include several entries for the local NSF not only remote peers. Storing local and remote information makes possible to specify that this NSF with identity A will use some particular authentication with remote NSF with identity B and what are the authentication mechanisms allowed to B.";

```
list pad-entry {
  key "name";
  ordered-by user;
  description
    "Peer Authorization Database (PAD) entry. It
     is a list of PAD entries ordered by the
     I2NSF Controller.";
  leaf name {
    type string;
    description
      "PAD unique name to identify this
       entry.";
  }
  choice identity {
    mandatory true;
    description
      "A particular IKE peer will be
       identified by one of these identities.
       This peer can be a remote peer or local
       peer (this NSF).";
    reference
      "Section 4.4.3.1 in RFC 4301";
    case ipv4-address{
      leaf ipv4-address {
        type inet:ipv4-address;
        description
          "Specifies the identity as a
           single four (4) octet.";
      }
    }
    case ipv6-address{
      leaf ipv6-address {
        type inet:ipv6-address;
        description
          "Specifies the identity as a
           single sixteen (16) octet IPv6
           address. An example is
```



```
                2001:DB8:0:0:8:800:200C:417A.";
            }
        }
    case fqdn-string {
        leaf fqdn-string {
            type inet:domain-name;
            description
                "Specifies the identity as a
                Fully-QualifiedDomain Name
                (FQDN) string. An example is:
                example.com. The string MUST
                NOT contain any terminators
                (e.g., NULL, CR, etc.).";
        }
    }
    case rfc822-address-string {
        leaf rfc822-address-string {
            type string;
            description
                "Specifies the identity as a
                fully-qualified RFC822 email
                address string. An example is,
                jsmith@example.com. The string
                MUST NOT contain any
                terminators e.g., NULL, CR,
                etc.).";
            reference
                "RFC 822.";
        }
    }
    case dnx509 {
        leaf dnx509 {
            type string;
            description
                "Specifies the identity as a
                ASN.1 X.500 Distinguished
                Name. An example is
                C=US,O=Example
                Organisation,CN=John Smith.";
            reference
                "RFC 2247.";
        }
    }
    case gn timer {
        leaf gn timer {
            type string;
            description
                "ASN.1 X.509 GeneralName. RFC
```



```
        3280.";
    }
}
case id-key {
    leaf id-key {
        type string;
        description
            "Opaque octet stream that may be
             used to pass vendor-specific
             information for proprietary
             types of identification.";
        reference
            "Section 3.5 in RFC 7296";
    }
}
case id-null {
    leaf id-null {
        type empty;
        description
            "ID_NULL identification used
             when IKE identification payload
             is not used." ;
        reference
            "RFC 7619";
    }
}
}
leaf auth-protocol {
    type auth-protocol-type;
    default ikev2;
    description
        "Only IKEv2 is supported right now but
         other authentication protocols may be
         supported in the future.";
}
container peer-authentication {
    description
        "This container allows the Security
         Controller to configure the
         authentication method (pre-shared key,
         eap, digital-signature, null) that
         will use a particular peer and the
         credentials, which will depend on the
         selected authentication method.";
    leaf auth-method {
        type auth-method-type;
        default pre-shared;
        description
```



```
        "Type of authentication method
        (pre-shared, eap, digital signature,
        null).";
    reference
        "Section 2.15 in RFC 7296";
}
container eap-method {
    when "../auth-method = 'eap'";
    leaf eap-type {
        type uint8;
        mandatory true;
        description
            "EAP method type. This
            information provides the
            particular EAP method to be
            used. Depending on the EAP
            method, pre-shared keys or
            certificates may be used.";
    }
    description
        "EAP method description used when
        authentication method is 'eap'.";
    reference
        "Section 2.16 in RFC 7296";
}
container pre-shared {
    when
        "../auth-method[.='pre-shared' or
        .='eap']";
    leaf secret {
        nacm:default-deny-all;
        type yang:hex-string;
        description
            "Pre-shared secret value. The
            NSF has to prevent read access
            to this value for security
            reasons.";
    }
    description
        "Shared secret value for PSK or
        EAP method authentication based on
        PSK.";
}
container digital-signature {
    when
        "../auth-method[.='digital-signature'
        or .='eap']";
    leaf ds-algorithm {
```



```
    type uint8;
    description
        "The digital signature
        algorithm is specified with a
        value extracted from the IANA
        Registry. Depending on the
        algorithm, the following leafs
        must contain information. For
        example if digital signature
        involves a certificate then leaf
        'cert-data' and 'private-key'
        will contain this information.";
    reference
        "IKEv2 Authentication Method -
        IANA Registry - Internet Key
        Exchange Version 2 (IKEv2)
        Parameters.";
}

choice public-key {
    mandatory true;
    leaf raw-public-key {
        type binary;
        description
            "A binary that contains the
            value of the public key. The
            interpretation of the content
            is defined by the digital
            signature algorithm. For
            example, an RSA key is
            represented as RSAPublicKey as
            defined in RFC 8017, and an
            Elliptic Curve Cryptography
            (ECC) key is represented
            using the 'publicKey'
            described in RFC 5915.";
        reference
            "RFC XXX: Common YANG Data
            Types for Cryptography.";
    }
    leaf cert-data {
        type ct:x509;
        description
            "X.509 certificate data -
            PEM4.";
        reference
            "RFC XXX: Common YANG Data
            Types for Cryptography.";
```



```
    }
    description
      "If the I2NSF Controller
      knows that the NSF
      already owns a private key
      associated to this public key
      (the NSF generated the pair
      public key/private key out of
      band), it will only configure
      one of the leaf of this
      choice. The NSF, based on
      the public key value can know
      the private key to be used.";
  }
  leaf private-key {
    nacm:default-deny-all;
    type binary;
    description
      "A binary that contains the
      value of the private key. The
      interpretation of the content
      is defined by the digital
      signature algorithm. For
      example, an RSA key is
      represented as RSAPrivateKey as
      defined in RFC 8017, and an
      Elliptic Curve Cryptography
      (ECC) key is represented as
      ECPrivateKey as defined in RFC
      5915.";
    reference
      "RFC XXX: Common YANG Data
      Types for Cryptography.";
  }
  leaf-list ca-data {
    type ct:x509;
    description
      "List of trusted Certification
      Authorities (CA) certificates
      encoded using ASN.1
      distinguished encoding rules
      (DER).";
    reference
      "RFC XXX: Common YANG Data
      Types for Cryptography.";
  }
  leaf crl-data {
    type ct:crl;
```



```
        description
            "A CertificateList structure, as
            specified in RFC 5280,
            encoded using ASN.1
            distinguished encoding rules
            (DER), as specified in ITU-T
            X.690.";
        reference
            "RFC XXX: Common YANG Data Types
            for Cryptography.";
    }
    leaf crl-uri {
        type inet:uri;
        description
            "X.509 CRL certificate URI.";
    }
    leaf oscp-uri {
        type inet:uri;
        description
            "OCSP URI.";
    }
    description
        "Digital Signature container.";

    } /*container digital-signature*/
} /*container peer-authentication*/
}

list conn-entry {
    key "name";
    description
        "IKE peer connection information. This list
        contains the IKE connection for this peer
        with other peers. This will be translated in
        real time by IKE Security Associations
        established with these nodes.";
    leaf name {
        type string;
        mandatory true;
        description
            "Identifier for this connection
            entry.";
    }
    leaf autostartup {
        type autostartup-type;
        default add;
        description
```



```
        "By-default: Only add configuration
        without starting the security
        association.";
    }
    leaf initial-contact {
        type boolean;
        default false;
        description
            "The goal of this value is to deactivate the
            usage of INITIAL_CONTACT notification
            (true). If this flag remains to false it
            means the usage of the INITIAL_CONTACT
            notification will depend on the IKEv2
            implementation.";
    }
    leaf version {
        type auth-protocol-type;
        default ikev2;
        description
            "IKE version. Only version 2 is supported
            so far.";
    }
    leaf fragmentation {
        type boolean;
        default false;
        description
            "Whether or not to enable IKE
            fragmentation as per RFC 7383 (true or
            false).";
        reference
            "RFC 7383.";
    }
    container ike-sa-lifetime-soft {
        description
            "IKE SA lifetime soft. Two lifetime values
            can be configured: either rekey time of the
            IKE SA or reauth time of the IKE SA. When
            the rekey lifetime expires a rekey of the
            IKE SA starts. When reauth lifetime
            expires a IKE SA reauthentication starts.";
        leaf rekey-time {
            type uint32;
            default 0;
            description
                "Time in seconds between each IKE SA
                rekey. The value 0 means infinite.";
        }
        leaf reauth-time {
```



```
        type uint32;
        default 0;
        description
            "Time in seconds between each IKE SA
             reauthentication. The value 0 means
             infinite.";
    }
    reference
        "Section 2.8 in RFC 7296.";
}
container ike-sa-lifetime-hard {
    description
        "Hard IKE SA lifetime. When this
         time is reached the IKE SA is removed.";
    leaf over-time {
        type uint32;
        default 0;
        description
            "Time in seconds before the IKE SA is
             removed. The value 0 means infinite.";
    }
    reference
        "RFC 7296.";
}
leaf-list authalg {
    type ic:integrity-algorithm-type;
    default 12;
    ordered-by user;
    description
        "Authentication algorithm for establishing
         the IKE SA. This list is ordered following
         from the higher priority to lower priority.
         First node of the list will be the algorithm
         with higher priority. If this list is empty
         the default integrity algorithm value assumed
         is NONE.";
}
leaf-list encalg {
    type ic:encryption-algorithm-type;
    default 12;
    ordered-by user;
    description
        "Encryption or AEAD algorithm for the IKE
         SAs. This list is ordered following
         from the higher priority to lower priority.
         First node of the list will be the algorithm
         with higher priority. If this list is empty
         the default encryption value assumed is
```



```
        NULL.";
    }
    leaf dh-group {
        type pfs-group;
        default 14;
        description
            "Group number for Diffie-Hellman
            Exponentiation used during IKE_SA_INIT
            for the IKE SA key exchange.";
    }
    leaf half-open-ike-sa-timer {
        type uint32;
        description
            "Set the half-open IKE SA timeout
            duration.";
        reference
            "Section 2 in RFC 7296";
    }

    leaf half-open-ike-sa-cookie-threshold {
        type uint32;
        description
            "Number of half-open IKE SAs that activate
            the cookie mechanism." ;
        reference
            "Section 2.6 in RFC 7296";
    }
    container local {
        leaf local-pad-entry-name {
            type string;
            description
                "Local peer authentication information.
                This node points to a specific entry in
                the PAD where the authorization
                information about this particular local
                peer is stored. It MUST match a
                pad-entry-name.";
        }
        description
            "Local peer authentication information.";
    }
    container remote {
        leaf remote-pad-entry-name {
            type string;
            description
                "Remote peer authentication information.
                This node points to a specific entry in
                the PAD where the authorization
```



```
        information about this particular
        remote peer is stored. It MUST match a
        pad-entry-name.";
    }
    description
        "Remote peer authentication information.";
}
container encapsulation-type
{
    uses ic:encap;
    description
        "This container carries configuration
        information about the source and destination
        ports of encapsulation that IKE should use
        and the type of encapsulation that
        should use when NAT traversal is required.
        However, this is just a best effort since
        the IKE implementation may need to use a
        different encapsulation as
        described in RFC 8229.";
    reference
        "RFC 8229.";
}
container spd {
    description
        "Configuration of the Security Policy
        Database (SPD). This main information is
        placed in the grouping
        ipsec-policy-grouping.";
    list spd-entry {
        key "name";
        ordered-by user;
        leaf name {
            type string;
            mandatory true;
            description
                "SPD entry unique name to identify
                the IPsec policy.";
        }
        container ipsec-policy-config {
            description
                "This container carries the
                configuration of a IPsec policy.";
            uses ic:ipsec-policy-grouping;
        }
        description
            "List of entries which will constitute
            the representation of the SPD. Since we
```



```
        have IKE in this case, it is only
        required to send a IPsec policy from
        this NSF where 'local' is this NSF and
        'remote' the other NSF. The IKE
        implementation will install IPsec
        policies in the NSF's kernel in both
        directions (inbound and outbound) and
        their corresponding IPsec SAs based on
        the information in this SPD entry.";
    }
    reference
        "Section 2.9 in RFC 7296";
}
container child-sa-info {
    leaf-list pfs-groups {
        type pfs-group;
        default 0;
        ordered-by user;
        description
            "If non-zero, it is required perfect
            forward secrecy when requesting new
            IPsec SA. The non-zero value is
            the required group number. This list is
            ordered following from the higher
            priority to lower priority. First node
            of the list will be the algorithm
            with higher priority.";
    }
    container child-sa-lifetime-soft {
        description
            "Soft IPsec SA lifetime soft.
            After the lifetime the action is
            defined in this container
            in the leaf action.";
        uses ic:lifetime;
        leaf action {
            type ic:lifetime-action;
            default replace;
            description
                "When the lifetime of an IPsec SA
                expires an action needs to be
                performed over the IPsec SA that
                reached the lifetime. There are
                three possible options:
                terminate-clear, terminate-hold and
                replace.";
        }
        reference
            "Section 4.5 in RFC 4301 and Section 2.8
```



```
        in RFC 7296.";
    }
}
container child-sa-lifetime-hard {
    description
        "IPsec SA lifetime hard. The action will
        be to terminate the IPsec SA.";
    uses ic:lifetime;
    reference
        "Section 2.8 in RFC 7296.";
}
description
    "Specific information for IPsec SAs
    SAs. It includes PFS group and IPsec SAs
    rekey lifetimes.";
}
container state {
    config false;

    leaf initiator {
        type boolean;
        description
            "It is acting as initiator for this
            connection.";
    }
    leaf initiator-ikesa-spi {
        type ike-spi;
        description
            "Initiator's IKE SA SPI.";
    }
    leaf responder-ikesa-spi {
        type ike-spi;
        description
            "Responder's IKE SA SPI.";
    }
    leaf nat-local {
        type boolean;
        description
            "True, if local endpoint is behind a
            NAT.";
    }
    leaf nat-remote {
        type boolean;
        description
            "True, if remote endpoint is behind
            a NAT.";
    }
}
```



```
    container encapsulation-type
    {
        uses ic:encap;
        description
            "This container provides information
            about the source and destination
            ports of encapsulation that IKE is
            using, and the type of encapsulation
            when NAT traversal is required.";
        reference
            "RFC 8229.";
    }
    leaf established {
        type uint64;
        description
            "Seconds since this IKE SA has been
            established.";
    }
    leaf current-rekey-time {
        type uint64;
        description
            "Seconds before IKE SA must be rekeyed.";
    }
    leaf current-reauth-time {
        type uint64;
        description
            "Seconds before IKE SA must be
            re-authenticated.";
    }
    description
        "IKE state data for a particular
        connection.";
    } /* ike-sa-state */
} /* ike-conn-entries */

container number-ike-sas {
    config false;
    leaf total {
        type uint64;
        description
            "Total number of active IKE SAs.";
    }
    leaf half-open {
        type uint64;
        description
            "Number of half-open active IKE SAs.";
    }
    leaf half-open-cookies {
```



```
        type uint64;
        description
            "Number of half open active IKE SAs with
             cookie activated.";
    }
    description
        "General information about the IKE SAs. In
         particular, it provides the current number of
         IKE SAs.";
    }
} /* container ipsec-ike */
}

<CODE ENDS>
```

[Appendix C](#). YANG model for IKE-less case

```
<CODE BEGINS> file "ietf-ipsec-ikeless@2019-08-05.yang"

module ietf-ipsec-ikeless {

    yang-version 1.1;
    namespace "urn:ietf:params:xml:ns:yang:ietf-ipsec-ikeless";

    prefix "ikeless";

    import ietf-yang-types { prefix yang; }

    import ietf-ipsec-common {
        prefix ic;
        reference
            "Common Data model for SDN-based IPsec
             configuration.";
    }

    import ietf-netconf-acm {
        prefix nacm;
        reference
            "RFC 8341: Network Configuration Access Control
             Model.";
    }

    organization "IETF I2NSF Working Group";
```


contact

"WG Web: <<https://datatracker.ietf.org/wg/i2nsf/about/>>

WG List: <<mailto:i2nsf@ietf.org>>

Author: Rafael Marin-Lopez
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Author: Fernando Pereniguez-Garcia
<[mailto:fernando.pereniguez@cud.upct.es](mailto:fernando.pereniguez@ cud.upct.es)>

";

description

"Data model for IKE-less case in the SDN-base IPsec flow protection service.

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This version of this YANG module is part of RFC XXXX;; see the RFC itself for full legal notices.

The key words 'MUST', 'MUST NOT', 'REQUIRED', 'SHALL', 'SHALL NOT', 'SHOULD', 'SHOULD NOT', 'RECOMMENDED', 'NOT RECOMMENDED', 'MAY', and 'OPTIONAL' in this document are to be interpreted as described in [BCP 14](#) ([RFC 2119](#)) ([RFC 8174](#)) when, and only when, they appear in all capitals, as shown here.";

```
revision "2019-08-05" {  
    description "Revision 06";  
    reference "RFC XXXX: YANG model for IKE case."  
}
```

```
container ipsec-ikeless {  
    description  
        "Container for configuration of the IKE-less  
        case. The container contains two additional
```



```
containers: 'spd' and 'sad'. The first allows the
I2NSF Controller to configure IPsec policies in
the Security Policy Database SPD, and the second
allows to configure IPsec Security Associations
(IPsec SAs) in the Security Association Database
(SAD).";
reference "RFC 4301";
container spd {
  description
    "Configuration of the Security Policy Database
    (SPD).";
  reference "Section 4.4.1.2 in RFC 4301";

  list spd-entry {
    key "name";
    ordered-by user;
    leaf name {
      type string;
      mandatory true;
      description
        "SPD entry unique name to identify this
        entry.";
    }
    leaf direction {
      type ic:ipsec-traffic-direction;
      description
        "Inbound traffic or outbound
        traffic. In the IKE-less case the
        I2NSF Controller needs to
        specify the policy direction to be
        applied in the NSF. In the IKE case
        this direction does not need to be
        specified since IKE
        will determine the direction that
        IPsec policy will require.";
    }
    leaf reqid {
      type uint64;
      default 0;
      description
        "This value allows to link this
        IPsec policy with IPsec SAs with the
        same reqid. It is only required in
        the IKE-less model since, in the IKE
        case this link is handled internally
        by IKE.";
    }
  }
}
```



```
    container ipsec-policy-config {
        description
            "This container carries the
            configuration of a IPsec policy.";
        uses ic:ipsec-policy-grouping;
    }
    description
        "The SPD is represented as a list of SPD
        entries, where each SPD entry represents an
        IPsec policy.";
    } /*list spd-entry*/
} /*container spd*/

container sad {
    description
        "Configuration of the IPsec Security Association
        Database (SAD)";
    reference "Section 4.4.2.1 in RFC 4301";
    list sad-entry {
        key "name";
        ordered-by user;
        leaf name {
            type string;
            description
                "SAD entry unique name to identify this
                entry.";
        }
        leaf reqid {
            type uint64;
            default 0;
            description
                "This value allows to link this
                IPsec SA with an IPsec policy with
                the same reqid.";
        }
    }

    container ipsec-sa-config {
        description
            "This container allows configuring
            details of an IPsec SA.";
        leaf spi {
            type uint32 { range "0..max"; }
            mandatory true;
            description
                "Security Parameter Index (SPI)'s
                IPsec SA.";
        }
        leaf ext-seq-num {
```



```
        type boolean;
        default true;
        description
            "True if this IPsec SA is using
             extended sequence numbers. True 64
             bit counter, FALSE 32 bit.";
    }
    leaf seq-number-counter {
        type uint64;
        default 0;
        description
            "A 64-bit counter when this IPsec
             SA is using Extended Sequence
             Number or 32-bit counter when it
             is not. It used to generate the
             initial Sequence Number field
             in ESP headers.";
    }
    leaf seq-overflow {
        type boolean;
        default false;
        description
            "The flag indicating whether
             overflow of the sequence number
             counter should prevent transmission
             of additional packets on the IPsec
             SA (false) and, therefore needs to
             be rekeyed, or whether rollover is
             permitted (true). If Authenticated
             Encryption with Associated Data
             (AEAD) is used this flag MUST BE
             false.";
    }
    leaf anti-replay-window {
        type uint32;
        default 32;
        description
            "A 32-bit counter and a bit-map (or
             equivalent) used to determine
             whether an inbound ESP packet is a
             replay. If set to 0 no anti-replay
             mechanism is performed.";
    }
    container traffic-selector {
        uses ic:selector-grouping;
        description
            "The IPsec SA traffic selector.";
    }
}
```



```
leaf protocol-parameters {
  type ic:ipsec-protocol-parameters;
  default esp;
  description
    "Security protocol of IPsec SA: Only
    ESP so far.";
}
leaf mode {
  type ic:ipsec-mode;
  description
    "Tunnel or transport mode.";
}
container esp-sa {
  when "../protocol-parameters =
  'esp'";
  description
    "In case the IPsec SA is
    Encapsulation Security Payload
    (ESP), it is required to specify
    encryption and integrity
    algorithms, and key material.";

  container encryption {
    description
      "Configuration of encryption or
      AEAD algorithm for IPsec
      Encapsulation Security Payload
      (ESP).";

    leaf encryption-algorithm {
      type ic:encryption-algorithm-type;
      description
        "Configuration of ESP
        encryption. With AEAD
        algorithms, the integrity
        node is not used.";
    }

    leaf key {
      nacm:default-deny-all;
      type yang:hex-string;
      description
        "ESP encryption key value.";
    }

    leaf iv {
      nacm:default-deny-all;
      type yang:hex-string;
      description
```



```
        "ESP encryption IV value.";
    }
}
container integrity {
    description
        "Configuration of integrity for
        IPsec Encapsulation Security
        Payload (ESP). This container
        allows to configure integrity
        algorithm when no AEAD
        algorithms are used, and
        integrity is required.";
    leaf integrity-algorithm {
        type ic:integrity-algorithm-type;
        description
            "Message Authentication Code
            (MAC) algorithm to provide
            integrity in ESP.";
    }
    leaf key {
        nacm:default-deny-all;
        type yang:hex-string;
        description
            "ESP integrity key value.";
    }
}
} /*container esp-sa*/

container sa-lifetime-hard {
    description
        "IPsec SA hard lifetime. The action
        associated is terminate and
        hold.";
    uses ic:lifetime;
}
container sa-lifetime-soft {
    description
        "IPsec SA soft lifetime.";
    uses ic:lifetime;
    leaf action {
        type ic:lifetime-action;
        description
            "Action lifetime:
            terminate-clear,
            terminate-hold or replace.";
    }
}
}
container tunnel {
```



```
        when "../mode = 'tunnel'";
        uses ic:tunnel-grouping;
        description
            "Endpoints of the IPsec tunnel.";
    }
    container encapsulation-type
    {
        uses ic:encap;
        description
            "This container carries
            configuration information about
            the source and destination ports
            which will be used for ESP
            encapsulation that ESP packets the
            type of encapsulation when NAT
            traversal is in place.";
    }
} /*ipsec-sa-config*/

container ipsec-sa-state {
    config false;
    description
        "Container describing IPsec SA state
        data.";
    container sa-lifetime-current {
        uses ic:lifetime;
        description
            "SAD lifetime current.";
    }
    container replay-stats {
        description
            "State data about the anti-replay
            window.";
        leaf replay-window {
            type uint64;
            description
                "Current state of the replay
                window.";
        }
        leaf packet-dropped {
            type uint64;
            description
                "Packets detected out of the
                replay window and dropped
                because they are replay
                packets.";
        }
    }
    leaf failed {
```



```
        type uint32;
        description
            "Number of packets detected out
            of the replay window.";
    }
    leaf seq-number-counter {
        type uint64;
        description
            "A 64-bit counter when this
            IPsec SA is using Extended
            Sequence Number or 32-bit
            counter when it is not.
            Current value of sequence
            number.";
    }
} /* container replay-stats*/
} /*ipsec-sa-state*/

description
    "List of SAD entries that conforms the SAD.";
} /*list sad-entry*/
} /*container sad*/
}/*container ipsec-ikeless*/

/* Notifications */
notification sadb-acquire {
    description
        "An IPsec SA is required. The traffic-selector
        container contains information about the IP packet
        that triggers the acquire notification.";
    leaf ipsec-policy-name {
        type string;
        mandatory true;
        description
            "It contains the SPD entry name (unique) of
            the IPsec policy that hits the IP packet
            required IPsec SA. It is assumed the
            I2NSF Controller will have a copy of the
            information of this policy so it can
            extract all the information with this
            unique identifier. The type of IPsec SA is
            defined in the policy so the Security
            Controller can also know the type of IPsec
            SA that must be generated.";
    }
    container traffic-selector {
        description
            "The IP packet that triggered the acquire
```



```
        and requires an IPsec SA. Specifically it
        will contain the IP source/mask and IP
        destination/mask; protocol (udp, tcp,
        etc...); and source and destination
        ports.";
    uses ic:selector-grouping;
}
}

notification sadb-expire {
    description "An IPsec SA expiration (soft or hard).";
    leaf ipsec-sa-name {
        type string;
        mandatory true;
        description
            "It contains the SAD entry name (unique) of
            the IPsec SA that has expired. It is assumed
            the I2NSF Controller will have a copy of the
            IPsec SA information (except the cryptographic
            material and state data) indexed by this name
            (unique identifier) so it can know all the
            information (crypto algorithms, etc.) about
            the IPsec SA that has expired in order to
            perform a rekey (soft lifetime) or delete it
            (hard lifetime) with this unique identifier.";
    }
    leaf soft-lifetime-expire {
        type boolean;
        default true;
        description
            "If this value is true the lifetime expired is
            soft. If it is false is hard.";
    }
    container lifetime-current {
        description
            "IPsec SA current lifetime. If
            soft-lifetime-expired is true this container is
            set with the lifetime information about current
            soft lifetime.";
        uses ic:lifetime;
    }
}

notification sadb-seq-overflow {
    description "Sequence overflow notification.";
    leaf ipsec-sa-name {
        type string;
        mandatory true;
        description
```



```

        "It contains the SAD entry name (unique) of
        the IPsec SA that is about to have sequence
        number overflow and rollover is not permitted.
        It is assumed the I2NSF Controller will have
        a copy of the IPsec SA information (except the
        cryptographic material and state data) indexed
        by this name (unique identifier) so the it can
        know all the information (crypto algorithms,
        etc.) about the IPsec SA that has expired in
        order to perform a rekey of the IPsec SA.";
    }
}
notification sadb-bad-spi {
    description
        "Notify when the NSF receives a packet with an
        incorrect SPI (i.e. not present in the SAD).";
    leaf spi {
        type uint32 { range "0..max"; }
        mandatory true;
        description
            "SPI number contained in the erroneous IPsec
            packet.";
    }
}
}/*module ietf-ipsec*/

<CODE ENDS>

```

[Appendix D](#). XML configuration example for IKE case (gateway-to-gateway)

This example shows a XML configuration file sent by the I2NSF Controller to establish a IPsec Security Association between two NSFs (see Figure 3) in tunnel mode (gateway-to-gateway) with ESP, authentication based on X.509 certificates and applying the IKE case.

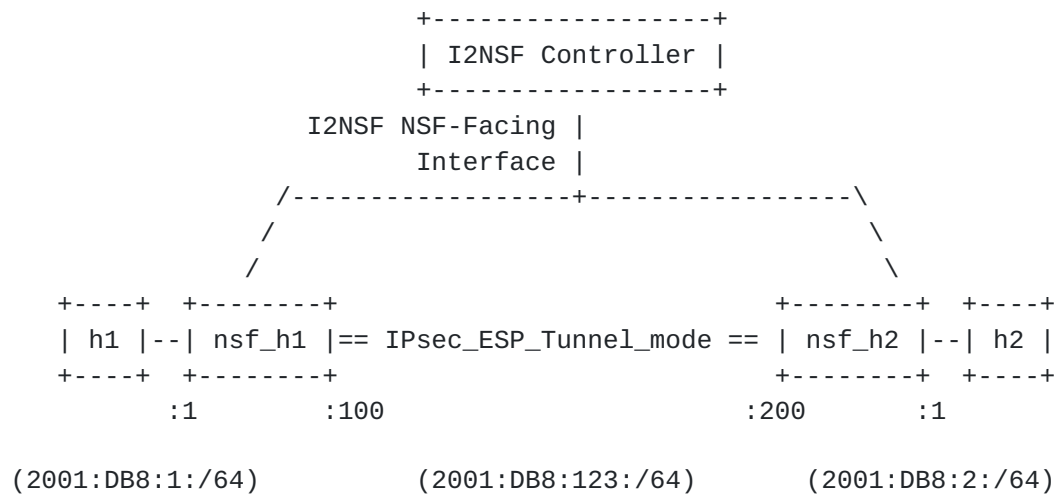


Figure 3: IKE case, tunnel mode , X.509 certificate authentication.

```
<ipsec-ike xmlns="urn:ietf:params:xml:ns:yang:ietf-ipsec-ike"
xmlns:nc="urn:ietf:params:xml:ns:netconf:base:1.0">
  <pad>
    <pad-entry>
      <name>nsf_h1_pad</name>
      <ipv6-address>2001:DB8:123::100</ipv6-address>
      <peer-authentication>
        <auth-method>digital-signature</auth-method>
        <digital-signature>
          <cert-data>base64encodedvalue==</cert-data>
          <private-key>base64encodedvalue==</private-key>
          <ca-data>base64encodedvalue==</ca-data>
        </digital-signature>
      </peer-authentication>
    </pad-entry>
    <pad-entry>
      <name>nsf_h2_pad</name>
      <ipv6-address>2001:DB8:123::200</ipv6-address>
      <auth-protocol>ikev2</auth-protocol>
      <peer-authentication>
        <auth-method>digital-signature</auth-method>
        <digital-signature>
          <!-- RSA Digital Signature -->
          <ds-algorithm>1</ds-algorithm>
          <cert-data>base64encodedvalue==</cert-data>
          <ca-data>base64encodedvalue==</ca-data>
        </digital-signature>
      </peer-authentication>
    </pad-entry>
  </pad>
</ipsec-ike>
```



```
</pad>
<conn-entry>
  <name>nsf_h1-nsf_h2</name>
  <autostartup>start</autostartup>
  <version>ikev2</version>
  <initial-contact>false</initial-contact>
  <fragmentation>true</fragmentation>
  <ike-sa-lifetime-soft>
    <rekey-time>60</rekey-time>
    <reauth-time>120</reauth-time>
  </ike-sa-lifetime-soft>
  <ike-sa-lifetime-hard>
    <over-time>3600</over-time>
  </ike-sa-lifetime-hard>
  <authalg>7</authalg>
  <!--AUTH_HMAC_SHA1_160-->
  <encalg>3</encalg>
  <!--ENCR_3DES -->
  <dh-group>18</dh-group>
  <!--8192-bit MODP Group-->
  <half-open-ike-sa-timer>30</half-open-ike-sa-timer>
  <half-open-ike-sa-cookie-threshold>
    15
  </half-open-ike-sa-cookie-threshold>
  <local>
    <local-pad-entry-name>nsf_h1_pad</local-pad-entry-name>
  </local>
  <remote>
    <remote-pad-entry-name>nsf_h2_pad</remote-pad-entry-name>
  </remote>
  <spd>
    <spd-entry>
      <name>nsf_h1-nsf_h2</name>
      <ipsec-policy-config>
        <anti-replay-window>32</anti-replay-window>
        <traffic-selector>
          <local-subnet>2001:DB8:1::0/64</local-subnet>
          <remote-subnet>2001:DB8:2::0/64</remote-subnet>
          <inner-protocol>any</inner-protocol>
          <local-ports>
            <start>0</start>
            <end>0</end>
          </local-ports>
          <remote-ports>
            <start>0</start>
            <end>0</end>
          </remote-ports>
        </traffic-selector>
```



```
<processing-info>
  <action>protect</action>
  <ipsec-sa-cfg>
    <pfp-flag>false</pfp-flag>
    <ext-seq-num>true</ext-seq-num>
    <seq-overflow>false</seq-overflow>
    <stateful-frag-check>false</stateful-frag-check>
    <mode>tunnel</mode>
    <protocol-parameters>esp</protocol-parameters>
    <esp-algorithms>
      <!-- AUTH_HMAC_SHA1_96 -->
      <integrity>2</integrity>
      <!-- ENCR_AES_CBC -->
      <encryption>12</encryption>
      <tfc-pad>false</tfc-pad>
    </esp-algorithms>
    <tunnel>
      <local>2001:DB8:123::100</local>
      <remote>2001:DB8:123::200</remote>
      <df-bit>clear</df-bit>
      <bypass-dscp>true</bypass-dscp>
      <ecn>false</ecn>
    </tunnel>
  </ipsec-sa-cfg>
</processing-info>
</ipsec-policy-config>
</spd-entry>
</spd>
<child-sa-info>
  <!-- 8192-bit MODP Group -->
  <pfs-groups>18</pfs-groups>
  <child-sa-lifetime-soft>
    <bytes>1000000</bytes>
    <packets>1000</packets>
    <time>30</time>
    <idle>60</idle>
    <action>replace</action>
  </child-sa-lifetime-soft>
  <child-sa-lifetime-hard>
    <bytes>2000000</bytes>
    <packets>2000</packets>
    <time>60</time>
    <idle>120</idle>
  </child-sa-lifetime-hard>
</child-sa-info>
</conn-entry>
</ipsec-ike>
```


Appendix E. XML configuration example for IKE-less case (host-to-host)

This example shows a XML configuration file sent by the I2NSF Controller to establish a IPsec Security Association between two NSF's (see Figure 4) in transport mode (host-to-host) with ESP, and applying the IKE-less case.

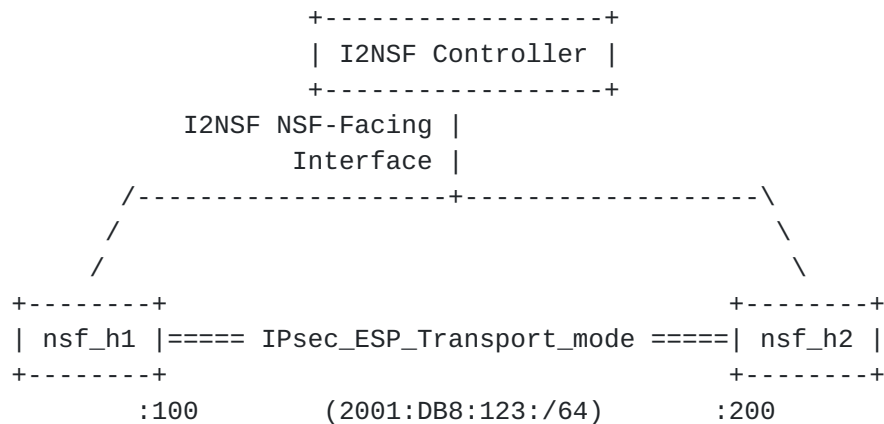


Figure 4: IKE-less case, transport mode.

```

<ipsec-ikeless
  xmlns="urn:ietf:params:xml:ns:yang:ietf-ipsec-ikeless"
  xmlns:nc="urn:ietf:params:xml:ns:netconf:base:1.0">
  <spd>
    <spd-entry>
      <name>
        in/trans/2001:DB8:123::200/2001:DB8:123::100
      </name>
      <direction>inbound</direction>
      <reqid>1</reqid>
      <ipsec-policy-config>
        <traffic-selector>
          <local-subnet>2001:DB8:123::200/128</local-subnet>
          <remote-subnet>2001:DB8:123::100/128</remote-subnet>
          <inner-protocol>any</inner-protocol>
          <local-ports>
            <start>0</start>
            <end>0</end>
          </local-ports>
          <remote-ports>
            <start>0</start>
            <end>0</end>
          </remote-ports>
        </traffic-selector>
      </ipsec-policy-config>
    </spd-entry>
  </spd>
</ipsec-ikeless>
  
```



```
        </remote-ports>
    </traffic-selector>
    <processing-info>
        <action>protect</action>
        <ipsec-sa-cfg>
            <ext-seq-num>true</ext-seq-num>
            <seq-overflow>true</seq-overflow>
            <mode>transport</mode>
            <protocol-parameters>esp</protocol-parameters>
            <esp-algorithms>
                <!--AUTH_HMAC_SHA1_96-->
                <integrity>2</integrity>
                <!--ENCR_AES_CBC -->
                <encryption>12</encryption>
            </esp-algorithms>
        </ipsec-sa-cfg>
    </processing-info>
</ipsec-policy-config>
</spd-entry>
<spd-entry>
    <name>out/trans/2001:DB8:123::100/2001:DB8:123::200</name>
    <direction>outbound</direction>
    <reqid>1</reqid>
    <ipsec-policy-config>
        <traffic-selector>
            <local-subnet>2001:DB8:123::100/128</local-subnet>
            <remote-subnet>2001:DB8:123::200/128</remote-subnet>
            <inner-protocol>any</inner-protocol>
            <local-ports>
                <start>0</start>
                <end>0</end>
            </local-ports>
            <remote-ports>
                <start>0</start>
                <end>0</end>
            </remote-ports>
        </traffic-selector>
        <processing-info>
            <action>protect</action>
            <ipsec-sa-cfg>
                <ext-seq-num>true</ext-seq-num>
                <seq-overflow>true</seq-overflow>
                <mode>transport</mode>
                <protocol-parameters>esp</protocol-parameters>
                <esp-algorithms>
                    <!-- AUTH_HMAC_SHA1_96 -->
                    <integrity>2</integrity>
                    <!-- ENCR_AES_CBC -->
```



```
        <encryption>12</encryption>
      </esp-algorithms>
    </ipsec-sa-cfg>
  </processing-info>
</ipsec-policy-config>
</spd-entry>
</spd>
<sad>
  <sad-entry>
    <name>out/trans/2001:DB8:123::100/2001:DB8:123::200</name>
    <reqid>1</reqid>
    <ipsec-sa-config>
      <spi>34501</spi>
      <ext-seq-num>true</ext-seq-num>
      <seq-number-counter>100</seq-number-counter>
      <seq-overflow>true</seq-overflow>
      <anti-replay-window>32</anti-replay-window>
      <traffic-selector>
        <local-subnet>2001:DB8:123::100/128</local-subnet>
        <remote-subnet>2001:DB8:123::200/128</remote-subnet>
        <inner-protocol>any</inner-protocol>
        <local-ports>
          <start>0</start>
          <end>0</end>
        </local-ports>
        <remote-ports>
          <start>0</start>
          <end>0</end>
        </remote-ports>
      </traffic-selector>
      <protocol-parameters>esp</protocol-parameters>
      <mode>transport</mode>
      <esp-sa>
        <encryption>
          <!-- //ENCR_AES_CBC -->
          <encryption-algorithm>12</encryption-algorithm>
          <key>01:23:45:67:89:AB:CE:DF</key>
          <iv>01:23:45:67:89:AB:CE:DF</iv>
        </encryption>
        <integrity>
          <!-- //AUTH_HMAC_SHA1_96 -->
          <integrity-algorithm>2</integrity-algorithm>
          <key>01:23:45:67:89:AB:CE:DF</key>
        </integrity>
      </esp-sa>
    </ipsec-sa-config>
  </sad-entry>
</sad-entry>
```



```
<name>in/trans/2001:DB8:123::200/2001:DB8:123::100</name>
<reqid>1</reqid>
<ipsec-sa-config>
  <spi>34502</spi>
  <ext-seq-num>true</ext-seq-num>
  <seq-number-counter>100</seq-number-counter>
  <seq-overflow>true</seq-overflow>
  <anti-replay-window>32</anti-replay-window>
  <traffic-selector>
    <local-subnet>2001:DB8:123::200/128</local-subnet>
    <remote-subnet>2001:DB8:123::100/128</remote-subnet>
    <inner-protocol>any</inner-protocol>
    <local-ports>
      <start>0</start>
      <end>0</end>
    </local-ports>
    <remote-ports>
      <start>0</start>
      <end>0</end>
    </remote-ports>
  </traffic-selector>
  <protocol-parameters>esp</protocol-parameters>
  <mode>transport</mode>
  <esp-sa>
    <encryption>
      <!-- //ENCR_AES_CBC -->
      <encryption-algorithm>12</encryption-algorithm>
      <key>01:23:45:67:89:AB:CE:DF</key>
      <iv>01:23:45:67:89:AB:CE:DF</iv>
    </encryption>
    <integrity>
      <!-- //AUTH_HMAC_SHA1_96 -->
      <integrity-algorithm>2</integrity-algorithm>
      <key>01:23:45:67:89:AB:CE:DF</key>
    </integrity>
  </esp-sa>
  <sa-lifetime-hard>
    <bytes>2000000</bytes>
    <packets>2000</packets>
    <time>60</time>
    <idle>120</idle>
  </sa-lifetime-hard>
  <sa-lifetime-soft>
    <bytes>1000000</bytes>
    <packets>1000</packets>
    <time>30</time>
    <idle>60</idle>
    <action>replace</action>
```



```
        </sa-lifetime-soft>
      </ipsec-sa-config>
    </sad-entry>
  </sad>
</ipsec-ikeless>
```

[Appendix F](#). XML notification examples

Below we show several XML files that represent different types of notifications defined in the IKE-less YANG model, which are sent by the NSF to the I2NSF Controller. The notifications happen in the IKE-less case.

```
<sadb-expire xmlns="urn:ietf:params:xml:ns:yang:ietf-ipsec-ikeless">
  <ipsec-sa-name>in/trans/2001:DB8:123::200/2001:DB8:123::100
</ipsec-sa-name>
  <soft-lifetime-expire>true</soft-lifetime-expire>
    <lifetime-current>
      <bytes>1000000</bytes>
      <packets>1000</packets>
      <time>30</time>
      <idle>60</idle>
    </lifetime-current>
</sadb-expire>
```

Figure 5: Example of sadb-expire notification.


```
<sadb-acquire xmlns="urn:ietf:params:xml:ns:yang:ietf-ipsec-ikeless">
  <ipsec-policy-name>in/trans/2001:DB8:123::200/2001:DB8:123::100
</ipsec-policy-name>
  <traffic-selector>
    <local-subnet>2001:DB8:123::200/128</local-subnet>
    <remote-subnet>2001:DB8:123::100/128</remote-subnet>
    <inner-protocol>any</inner-protocol>
    <local-ports>
      <start>0</start>
      <end>0</end>
    </local-ports>
    <remote-ports>
      <start>0</start>
      <end>0</end>
    </remote-ports>
  </traffic-selector>
</sadb-acquire>
```

Figure 6: Example of sadb-acquire notification.

```
<sadb-seq-overflow
  xmlns="urn:ietf:params:xml:ns:yang:ietf-ipsec-ikeless">
  <ipsec-sa-name>in/trans/2001:DB8:123::200/2001:DB8:123::100
  </ipsec-sa-name>
</sadb-seq-overflow>
```

Figure 7: Example of sadb-seq-overflow notification.

```
<sadb-bad-spi
  xmlns="urn:ietf:params:xml:ns:yang:ietf-ipsec-ikeless">
  <spi>666</spi>
</sadb-bad-spi>
```

Figure 8: Example of sadb-bad-spi notification.

[Appendix G](#). Operational use cases examples

[G.1](#). Example of IPsec SA establishment

This appendix exemplifies the applicability of IKE case and IKE-less case to traditional IPsec configurations, that is, host-to-host and gateway-to-gateway. The examples we show in the following assume the existence of two NSFs needing to establish an end-to-end IPsec SA to

protect their communications. Both NSF's could be two hosts that exchange traffic (host-to-host) or gateways (gateway-to-gateway), for example, within an enterprise that needs to protect the traffic between the networks of two branch offices.

Applicability of these configurations appear in current and new networking scenarios. For example, SD-WAN technologies are providing dynamic and on-demand VPN connections between branch offices, or between branches and SaaS cloud services. Beside, IaaS services providing virtualization environments are deployments solutions based on IPsec to provide secure channels between virtual instances (host-to-host) and providing VPN solutions for virtualized networks (gateway-to-gateway).

As we will show in the following, the I2NSF-based IPsec management system (for IKE and IKE-less cases), exhibits various advantages:

1. It allows to create IPsec SAs among two NSF's, based only on the application of general Flow-based Protection Policies at the I2NSF User. Thus, administrators can manage all security associations in a centralized point with an abstracted view of the network.
2. Any NSF deployed in the system does not need manual configuration, therefore allowing its deployment in an automated manner.

G.1.1. IKE case

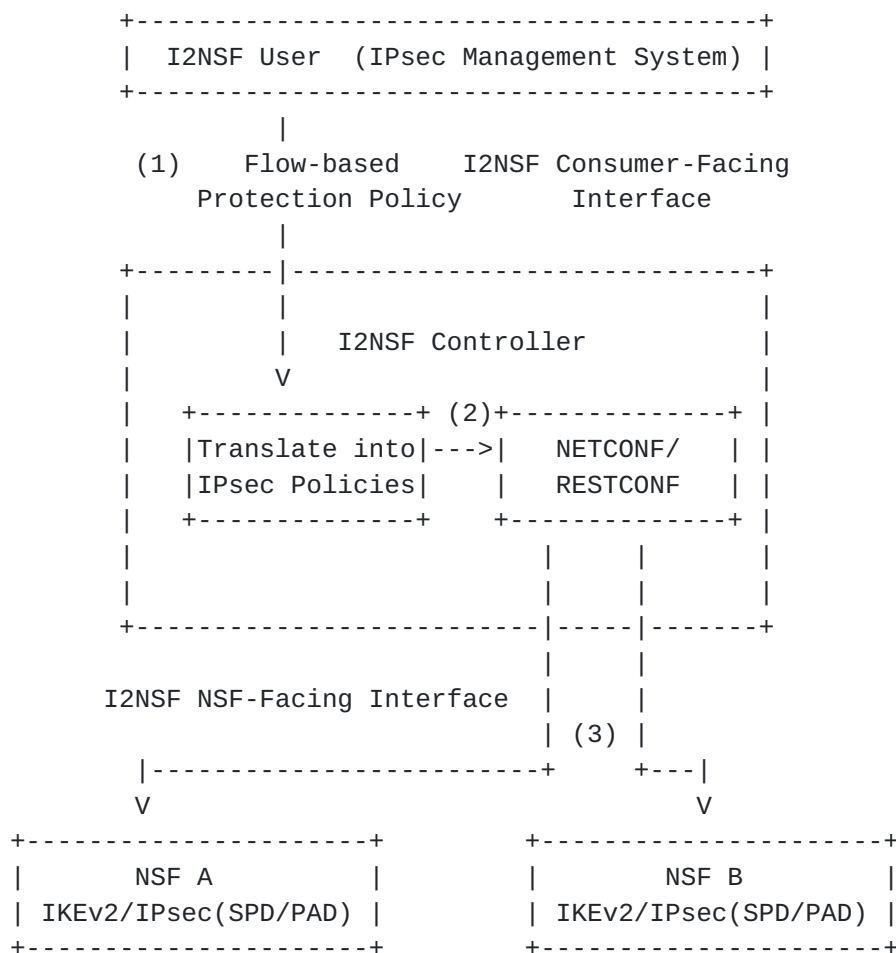


Figure 9: Host-to-host / gateway-to-gateway for the IKE case.

Figure 9 describes the application of the IKE case when a data packet needs to be protected in the path between the NSF A and NSF B:

1. The I2NSF User defines a general flow-based protection policy (e.g. protect data traffic between NSF A and B). The I2NSF Controller looks for the NSFs involved (NSF A and NSF B).
2. The I2NSF Controller generates IKEv2 credentials for them and translates the policies into SPD and PAD entries.
3. The I2NSF Controller inserts an IKEv2 configuration that includes the SPD and PAD entries in both NSF A and NSF B. If some of operations with NSF A and NSF B fail the I2NSF Controller will stop the process and perform a rollback operation by deleting any IKEv2, SPD and PAD configuration that had been successfully installed in NSF A or B.

If the previous steps are successful, the flow is protected by means of the IPsec SA established with IKEv2 between NSF A and NSF B.

[G.1.2.](#) IKE-less case

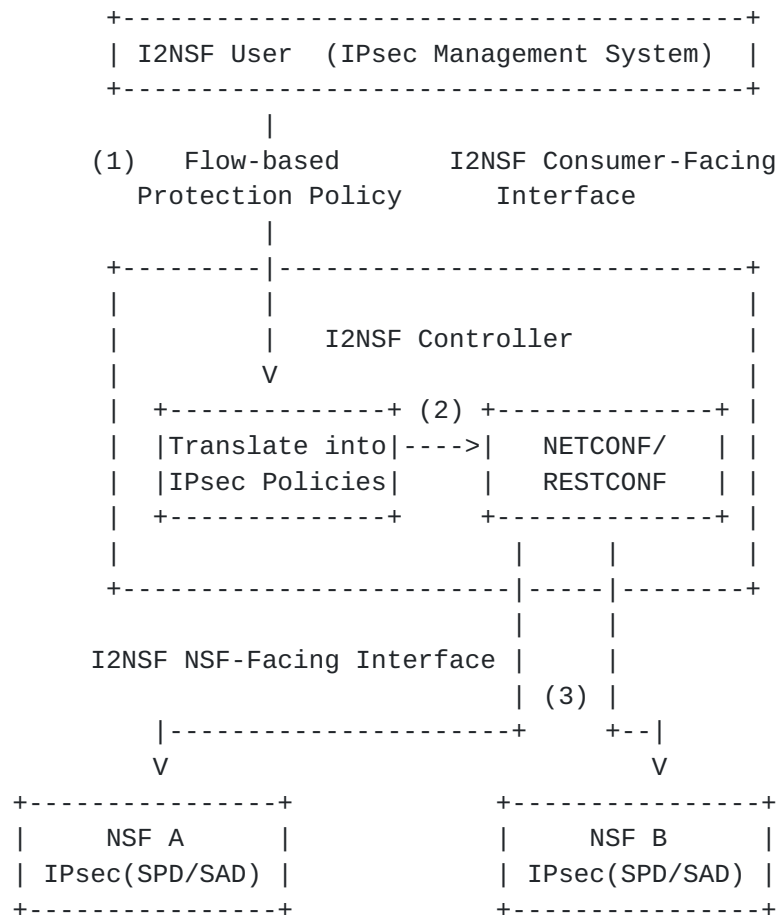


Figure 10: Host-to-host / gateway-to-gateway for IKE-less case.

Figure 10 describes the application of the IKE-less case when a data packet needs to be protected in the path between the NSF A and NSF B:

1. The I2NSF User establishes a general Flow-based Protection Policy and the I2NSF Controller looks for the involved NSFs.
2. The I2NSF Controller translates the flow-based security policies into IPsec SPD and SAD entries.
3. The I2NSF Controller inserts these entries in both NSF A and NSF B IPsec databases (SPD and SAD). The following text describes how this would happen:

- * The I2NSF Controller chooses two random values as SPIs: for example, SPIa1 for NSF A and SPIb1 for NSF B. These numbers MUST NOT be in conflict with any IPsec SA in NSF A or NSF B. It also generates fresh cryptographic material for the new inbound/outbound IPsec SAs and their parameters.
- * After that, the I2NSF Controller sends simultaneously the new inbound IPsec SA with SPIa1 and new outbound IPsec SA with SPIb1 to NSF A; and the new inbound IPsec SA with SPIb1 and new outbound IPsec SA with SPIa1 to B, together with the corresponding IPsec policies.
- * Once the I2NSF Controller receives confirmation from NSF A and NSF B, it knows that the IPsec SAs are correctly installed and ready.

Other alternative to this operation is: the I2NSF Controller sends first the IPsec policies and new inbound IPsec SAs to A and B and once it obtains a successful confirmation of these operations from NSF A and NSF B, it proceeds with installing to the new outbound IPsec SAs. Despite this procedure may increase the latency to complete the process, no traffic is sent over the network until the IPsec SAs are completely operative. In any case other alternatives MAY be possible to implement step 3.

4. If some of the operations described above fails (e.g. the NSF A reports an error when the I2NSF Controller is trying to install the SPD entry, the new inbound or outbound IPsec SAs) the I2NSF Controller must perform rollback operations by deleting any new inbound or outbound SA and SPD entry that had been successfully installed in any of the NSFs (e.g NSF B) and stop the process. Note that the I2NSF Controller may retry several times before giving up.
5. Otherwise, if the steps 1 to 3 are successful, the flow between NSF A and NSF B is protected by means of the IPsec SAs established by the I2NSF Controller. It is worth mentioning that the I2NSF Controller associates a lifetime to the new IPsec SAs. When this lifetime expires, the NSF will send a sadb-expire notification to the I2NSF Controller in order to start the rekeying process.

Instead of installing IPsec policies (in the SPD) and IPsec SAs (in the SAD) in step 3 (proactive mode), it is also possible that the I2NSF Controller only installs the SPD entries in step 3 (reactive mode). In such a case, when a data packet requires to be protected with IPsec, the NSF that saw first the data packet will send a sadb-acquire notification that informs the I2NSF Controller that needs SAD

entries with the IPsec SAs to process the data packet. In such as reactive mode, upon reception of the sadb-acquire notification, the I2NSF Controller installs the new IPsec SAs in NSF A and B (following the procedure previously described in step 3) but without sending any IPsec policies, since IPsec policies are already installed in the SPD. Again, if some of the operations installing the new inbound/outbound IPsec SAs fail, the I2NSF Controller stops the process and performs a rollback operation by deleting any new inbound/outbound SAs that had been successfully installed.

G.2. Example of the rekeying process in IKE-less case

To explain an example of the rekeying process between two IPsec NSFs A and B, let assume that SPIa1 identifies the inbound IPsec SA in A, and SPIb1 the inbound IPsec SA in B. The rekeying process will take the following steps:

1. The I2NSF Controller chooses two random values as SPI for the new inbound IPsec SAs: for example, SPIa2 for A and SPIb2 for B. These numbers MUST NOT be in conflict with any IPsec SA in A or B. Then, the I2NSF Controller creates an inbound IPsec SA with SPIa2 in A and another inbound IPsec SA in B with SPIb2. It can send this information simultaneously to A and B.
2. Once the I2NSF Controller receives confirmation from A and B, the controller knows that the inbound IPsec SAs are correctly installed. Then it proceeds to send in parallel to A and B, the outbound IPsec SAs: the outbound IPsec SA to A with SPIb2, and the outbound IPsec SA to B with SPIa2. At this point the new IPsec SAs are ready.
3. Once the I2NSF Controller receives confirmation from A and B that the outbound IPsec SAs have been installed, the I2NSF Controller, in parallel, deletes the old IPsec SAs from A (inbound SPIa1 and outbound SPIb1) and B (outbound SPIa1 and inbound SPIb1).

If some of the operations in step 1 fail (e.g. the NSF A reports an error when the I2NSF Controller is trying to install a new inbound IPsec SA) the I2NSF Controller must perform rollback operations by removing any new inbound SA that had been successfully installed during step 1.

If step 1 is successful but some of the operations in step 2 fails (e.g. the NSF A reports an error when the I2NSF Controller is trying to install the new outbound IPsec SA), the I2NSF Controller must perform a rollback operation by deleting any new outbound SA that had been successfully installed during step 2 and by deleting the inbound SAs created in step 1.

If the steps 1 and 2 are successful and the step 3 fails, the I2NSF Controller will avoid any rollback of the operations carried out in step 1 and step 2 since new and valid IPsec SAs were created and are functional. The I2NSF Controller may reattempt to remove the old inbound and outbound SAs in NSF A and NSF B several times until it receives a success or it gives up. In the last case, the old IPsec SAs will be removed when their corresponding hard lifetime is reached.

G.3. Example of managing NSF state loss in IKE-less case

In the IKE-less case, if the I2NSF Controller detects that a NSF has lost the IPsec state, it could follow the next steps:

1. The I2NSF Controller SHOULD delete the old IPsec SAs on the non-failed nodes, established with the failed node. This prevents the non-failed nodes from leaking plaintext.
2. If the affected node restarts, the I2NSF Controller configures the new inbound IPsec SAs between the affected node and all the nodes it was talking to.
3. After these inbound IPsec SAs have been established, the I2NSF Controller configures the outbound IPsec SAs in parallel.

Step 2 and step 3 can be performed at the same time at the cost of a potential packet loss. If this is not critical then it is an optimization since the number of exchanges between I2NSF Controller and NSFs is lower.

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