
Stream: Internet Engineering Task Force (IETF)
RFC: [9640](#)
Category: Standards Track
Published: October 2024
ISSN: 2070-1721
Author: K. Watsen
Watsen Networks

RFC 9640

YANG Data Types and Groupings for Cryptography

Abstract

This document presents a YANG 1.1 (RFC 7950) module defining identities, typedefs, and groupings useful to cryptographic applications.

Status of This Memo

This is an Internet Standards Track document.

This document is a product of the Internet Engineering Task Force (IETF). It represents the consensus of the IETF community. It has received public review and has been approved for publication by the Internet Engineering Steering Group (IESG). Further information on Internet Standards is available in Section 2 of RFC 7841.

Information about the current status of this document, any errata, and how to provide feedback on it may be obtained at <https://www.rfc-editor.org/info/rfc9640>.

Copyright Notice

Copyright (c) 2024 IETF Trust and the persons identified as the document authors. All rights reserved.

This document is subject to BCP 78 and the IETF Trust's Legal Provisions Relating to IETF Documents (<https://trustee.ietf.org/license-info>) in effect on the date of publication of this document. Please review these documents carefully, as they describe your rights and restrictions with respect to this document. Code Components extracted from this document must include Revised BSD License text as described in Section 4.e of the Trust Legal Provisions and are provided without warranty as described in the Revised BSD License.

Table of Contents

1. Introduction	3
1.1. Relation to Other RFCs	3
1.2. Specification Language	4
1.3. Adherence to the NMDA	4
1.4. Conventions	4
2. The "ietf-crypto-types" Module	4
2.1. Data Model Overview	5
2.2. Example Usage	14
2.3. YANG Module	21
3. Security Considerations	40
3.1. No Support for CRMF	40
3.2. No Support for Key Generation	41
3.3. Unconstrained Public Key Usage	41
3.4. Unconstrained Private Key Usage	41
3.5. Cleartext Passwords and Keys	41
3.6. Encrypting Passwords and Keys	41
3.7. Deletion of Cleartext Key Values	42
3.8. Considerations for the "ietf-crypto-types" YANG Module	42
4. IANA Considerations	43
4.1. The IETF XML Registry	43
4.2. The YANG Module Names Registry	44
5. References	44
5.1. Normative References	44
5.2. Informative References	46
Acknowledgements	47
Author's Address	47

1. Introduction

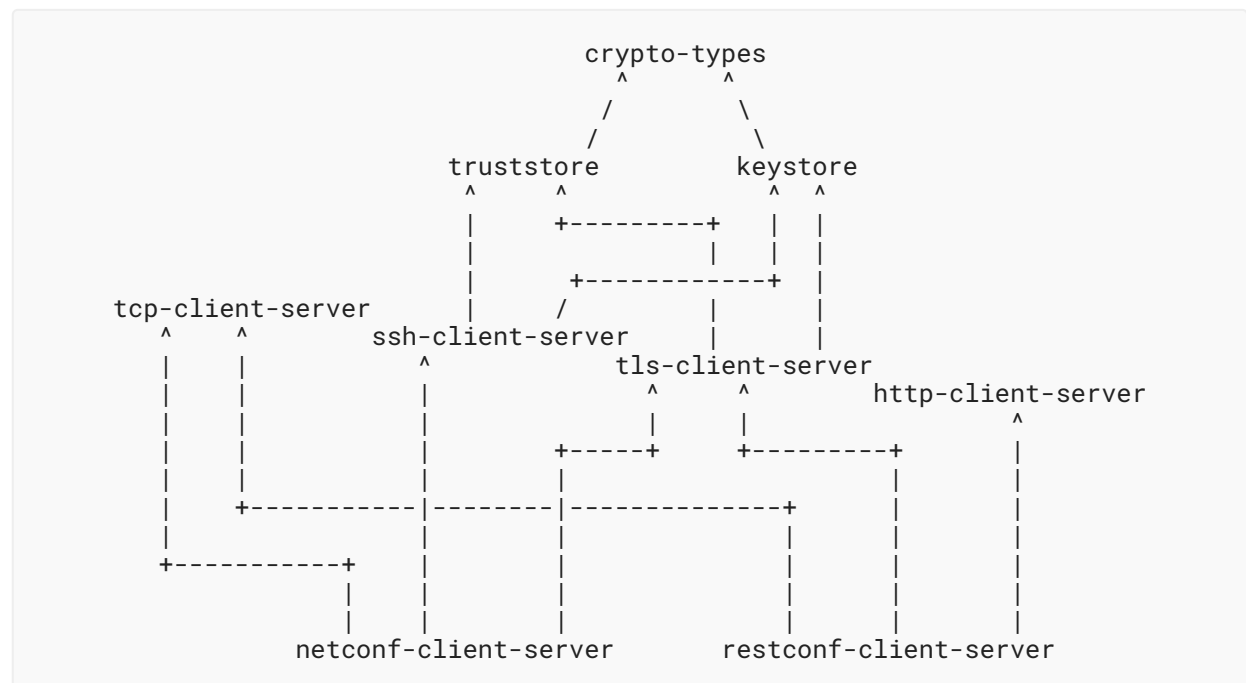
This document presents a YANG 1.1 [RFC7950] module defining identities, typedefs, and groupings useful to cryptographic applications.

1.1. Relation to Other RFCs

This document presents a YANG module [RFC7950] that is part of a collection of RFCs that work together to, ultimately, support the configuration of both the clients and servers of both the Network Configuration Protocol (NETCONF) [RFC6241] and RESTCONF [RFC8040].

The dependency relationship between the primary YANG groupings defined in the various RFCs is presented in the below diagram. In some cases, a document may define secondary groupings that introduce dependencies not illustrated in the diagram. The labels in the diagram are shorthand names for the defining RFCs. The citation references for the shorthand names are provided below the diagram.

Please note that the arrows in the diagram point from referencer to referenced. For example, the "crypto-types" RFC does not have any dependencies, whilst the "keystore" RFC depends on the "crypto-types" RFC.



Label in Diagram	Reference
crypto-types	RFC 9640
truststore	[RFC9641]

keystore	[RFC9642]
tcp-client-server	[RFC9643]
ssh-client-server	[RFC9644]
tls-client-server	[RFC9645]
http-client-server	[HTTP-CLIENT-SERVER]
netconf-client-server	[NETCONF-CLIENT-SERVER]
restconf-client-server	[RESTCONF-CLIENT-SERVER]

Table 1: Labels in Diagram to RFC Mapping

1.2. Specification 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 BCP 14 [RFC2119] [RFC8174] when, and only when, they appear in all capitals, as shown here.

1.3. Adherence to the NMDA

This document is compliant with the Network Management Datastore Architecture (NMDA) [RFC8342]. It does not define any protocol-accessible nodes that are "config false".

1.4. Conventions

Various examples in this document use "BASE64VALUE=" as a placeholder value for binary data that has been base64 encoded (per Section 9.8 of [RFC7950]). This placeholder value is used because real base64-encoded structures are often many lines long and hence distracting to the example being presented.

Various examples in this document use the XML [W3C.REC-xml-20081126] encoding. Other encodings, such as JSON [RFC8259], could alternatively be used.

Various examples in this document contain long lines that may be folded, as described in [RFC8792].

2. The "ietf-crypto-types" Module

This section defines a YANG 1.1 [RFC7950] module called "ietf-crypto-types". A high-level overview of the module is provided in Section 2.1. Examples illustrating the module's use are provided in Section 2.2. The YANG module itself is defined in Section 2.3.

2.1. Data Model Overview

This section provides an overview of the "ietf-crypto-types" module in terms of its features, identities, typedefs, and groupings.

2.1.1. Features

The following diagram lists all the "feature" statements defined in the "ietf-crypto-types" module:

```
Features:
+-- one-symmetric-key-format
+-- one-asymmetric-key-format
+-- symmetrically-encrypted-value-format
+-- asymmetrically-encrypted-value-format
+-- cms-enveloped-data-format
+-- cms-encrypted-data-format
+-- p10-csr-format
+-- csr-generation
+-- certificate-expiration-notification
+-- cleartext-passwords
+-- encrypted-passwords
+-- cleartext-symmetric-keys
+-- hidden-symmetric-keys
+-- encrypted-symmetric-keys
+-- cleartext-private-keys
+-- hidden-private-keys
+-- encrypted-private-keys
```

The diagram above uses syntax that is similar to but not the same as that in [\[RFC8340\]](#).

2.1.2. Identities

The following diagram illustrates the hierarchical relationship amongst the "identity" statements defined in the "ietf-crypto-types" module:

```

Identities:
+-- public-key-format
| +-- subject-public-key-info-format
| +-- ssh-public-key-format
+-- private-key-format
| +-- rsa-private-key-format
| +-- ec-private-key-format
| +-- one-asymmetric-key-format
|   {one-asymmetric-key-format}?
+-- symmetric-key-format
| +-- octet-string-key-format
| +-- one-symmetric-key-format
|   {one-symmetric-key-format}?
+-- encrypted-value-format
| +-- symmetrically-encrypted-value-format
| |   {symmetrically-encrypted-value-format}?
| | +-- cms-encrypted-data-format
| |   {cms-encrypted-data-format}?
| +-- asymmetrically-encrypted-value-format
| |   {asymmetrically-encrypted-value-format}?
| | +-- cms-enveloped-data-format
| |   {cms-enveloped-data-format}?
+-- csr-format
| +-- p10-csr-format {p10-csr-format?}

```

The diagram above uses syntax that is similar to but not the same as that in [\[RFC8340\]](#).

Comments:

- The diagram shows that there are five base identities. The first three identities are used to indicate the format for the key data, while the fourth identity is used to indicate the format for encrypted values. The fifth identity is used to indicate the format for a certificate signing request (CSR). The base identities are "abstract", in the object oriented programming sense, in that they only define a "class" of formats, rather than a specific format.
- The various terminal identities define specific encoding formats. The derived identities defined in this document are sufficient for the effort described in [Section 1.1](#), but by nature of them being identities, additional derived identities **MAY** be defined by future efforts.
- Identities used to specify uncommon formats are enabled by "feature" statements, allowing applications to support them when needed.

2.1.3. Typedefs

The following diagram illustrates the relationship amongst the "typedef" statements defined in the "ietf-crypto-types" module:

```
Typedefs:
  binary
    +-- csr-info
    +-- csr
    +-- x509
    | +-- trust-anchor-cert-x509
    | +-- end-entity-cert-x509
    +-- crl
    +-- ocsf-request
    +-- ocsf-response
    +-- cms
      +-- data-content-cms
      +-- signed-data-cms
      | +-- trust-anchor-cert-cms
      | +-- end-entity-cert-cms
      +-- enveloped-data-cms
      +-- digested-data-cms
      +-- encrypted-data-cms
      +-- authenticated-data-cms
```

The diagram above uses syntax that is similar to but not the same as that in [\[RFC8340\]](#).

Comments:

- All the typedefs defined in the "ietf-crypto-types" module extend the "binary" type defined in [\[RFC7950\]](#).
- Additionally, all the typedefs define a type for encoding an ASN.1 [\[ITU.X680.2021\]](#) structure using DER [\[ITU.X690.2021\]](#).
- The "trust-anchor-*" and "end-entity-*" typedefs are syntactically identical to their base typedefs and only distinguish themselves by the expected nature of their content. These typedefs are defined to facilitate common modeling needs.

2.1.4. Groupings

The "ietf-crypto-types" module defines the following "grouping" statements:

- encrypted-value-grouping
- password-grouping
- symmetric-key-grouping
- public-key-grouping
- private-key-grouping
- asymmetric-key-pair-grouping
- certificate-expiration-grouping
- trust-anchor-cert-grouping
- end-entity-cert-grouping
- generate-csr-grouping
- asymmetric-key-pair-with-cert-grouping
- asymmetric-key-pair-with-certs-grouping

Each of these groupings are presented in the following subsections.

2.1.4.1. The "encrypted-value-grouping" Grouping

The following tree diagram [RFC8340] illustrates the "encrypted-value-grouping" grouping:

```
grouping encrypted-value-grouping:
  +-- encrypted-by
  +-- encrypted-value-format    identityref
  +-- encrypted-value          binary
```

Comments:

- The "encrypted-by" node is an empty container (difficult to see in the diagram) that a consuming module **MUST** augment key references into. The "ietf-crypto-types" module is unable to populate this container as the module only defines groupings. [Section 2.2.1](#) presents an example illustrating a consuming module populating the "encrypted-by" container.
- The "encrypted-value" node is the value encrypted by the key referenced by the "encrypted-by" node and encoded in the format appropriate for the kind of key it was encrypted by.
 - If the value is encrypted by a symmetric key, then the encrypted value is encoded using the format associated with the "symmetrically-encrypted-value-format" identity.
 - If the value is encrypted by an asymmetric key, then the encrypted value is encoded using the format associated with the "asymmetrically-encrypted-value-format" identity.

See [Section 2.1.2](#) for information about the "format" identities.

2.1.4.2. The "password-grouping" Grouping

This section presents a tree diagram [RFC8340] illustrating the "password-grouping" grouping. This tree diagram does not expand the internally used "grouping" statement(s):

```
grouping password-grouping:
  +-- (password-type)
    +--:(cleartext-password) {cleartext-passwords}?
      | +-- cleartext-password? string
    +--:(encrypted-password) {encrypted-passwords}?
      +-- encrypted-password
      +---u encrypted-value-grouping
```

Comments:

- The "password-grouping" enables the configuration of credentials needed to authenticate to a remote system. The "ianach:crypt-hash" typedef from [RFC7317] should be used instead when needing to configure a password to authenticate a local account.
- For the referenced "grouping" statement(s):
 - The "encrypted-value-grouping" grouping is discussed in [Section 2.1.4.1](#).

- The "choice" statement enables the password data to be cleartext or encrypted, as follows:
 - The "cleartext-password" node can encode any cleartext value.
 - The "encrypted-password" node is an instance of the "encrypted-value-grouping" discussed in [Section 2.1.4.1](#).

2.1.4.3. The "symmetric-key-grouping" Grouping

This section presents a tree diagram [RFC8340] illustrating the "symmetric-key-grouping" grouping. This tree diagram does not expand the internally used "grouping" statement(s):

```
grouping symmetric-key-grouping:
  +-- key-format?                identityref
  +-- (key-type)
    +--:(cleartext-symmetric-key)
      | +-- cleartext-symmetric-key?  binary
      |   {cleartext-symmetric-keys}?
    +--:(hidden-symmetric-key) {hidden-symmetric-keys}?
      | +-- hidden-symmetric-key?    empty
    +--:(encrypted-symmetric-key) {encrypted-symmetric-keys}?
      +-- encrypted-symmetric-key
        +---u encrypted-value-grouping
```

Comments:

- For the referenced "grouping" statement(s):
 - The "encrypted-value-grouping" grouping is discussed in [Section 2.1.4.1](#).
- The "key-format" node is an identity-reference to the "symmetric-key-format" abstract base identity discussed in [Section 2.1.2](#), enabling the symmetric key to be encoded using any of the formats defined by the derived identities.
- The "choice" statement enables the private key data to be cleartext, encrypted, or hidden, as follows:
 - The "cleartext-symmetric-key" node can encode any cleartext key value.
 - The "hidden-symmetric-key" node is of type "empty" as the real value cannot be presented via the management interface.
 - The "encrypted-symmetric-key" node's structure is discussed in [Section 2.1.4.1](#).

2.1.4.4. The "public-key-grouping" Grouping

This section presents a tree diagram [RFC8340] illustrating the "public-key-grouping" grouping. This tree diagram does not expand any internally used "grouping" statement(s):

```
grouping public-key-grouping:
  +-- public-key-format          identityref
  +-- public-key                 binary
```

Comments:

- The "public-key-format" node is an identity-reference to the "public-key-format" abstract base identity discussed in [Section 2.1.2](#), enabling the public key to be encoded using any of the formats defined by the derived identities.
- The "public-key" node is the public key data in the selected format. No "choice" statement is used to hide or encrypt the public key data because it is unnecessary to do so for public keys.

2.1.4.5. The "private-key-grouping" Grouping

This section presents a tree diagram [[RFC8340](#)] illustrating the "private-key-grouping" grouping. This tree diagram does not expand the internally used "grouping" statement(s):

```
grouping private-key-grouping:
  +-- private-key-format?          identityref
  +-- (private-key-type)
    +--:(cleartext-private-key) {cleartext-private-keys}?
    | +-- cleartext-private-key?  binary
    +--:(hidden-private-key) {hidden-private-keys}?
    | +-- hidden-private-key?    empty
    +--:(encrypted-private-key) {encrypted-private-keys}?
      +-- encrypted-private-key
      +---u encrypted-value-grouping
```

Comments:

- For the referenced "grouping" statement(s):
 - The "encrypted-value-grouping" grouping is discussed in [Section 2.1.4.1](#).
- The "private-key-format" node is an identity-reference to the "private-key-format" abstract base identity discussed in [Section 2.1.2](#), enabling the private key to be encoded using any of the formats defined by the derived identities.
- The "choice" statement enables the private key data to be cleartext, encrypted, or hidden, as follows:
 - The "cleartext-private-key" node can encode any cleartext key value.
 - The "hidden-private-key" node is of type "empty" as the real value cannot be presented via the management interface.
 - The "encrypted-private-key" node's structure is discussed in [Section 2.1.4.1](#).

2.1.4.6. The "asymmetric-key-pair-grouping" Grouping

This section presents a tree diagram [[RFC8340](#)] illustrating the "asymmetric-key-pair-grouping" grouping. This tree diagram does not expand the internally used "grouping" statement(s):

```
grouping asymmetric-key-pair-grouping:
  +---u public-key-grouping
  +---u private-key-grouping
```

Comments:

- For the referenced "grouping" statement(s):
 - The "public-key-grouping" grouping is discussed in [Section 2.1.4.4](#).
 - The "private-key-grouping" grouping is discussed in [Section 2.1.4.5](#).

2.1.4.7. The "certificate-expiration-grouping" Grouping

This section presents a tree diagram [RFC8340] illustrating the "certificate-expiration-grouping" grouping:

```
grouping certificate-expiration-grouping:
  +---n certificate-expiration
        {certificate-expiration-notification}?
  +-- expiration-date      yang:date-and-time
```

Comments:

- This grouping's only purpose is to define the "certificate-expiration" notification statement, used by the groupings defined in Sections [2.1.4.8](#) and [2.1.4.9](#).
- The "certificate-expiration" notification enables servers to notify clients when certificates are nearing expiration.
- The "expiration-date" node indicates when the designated certificate will (or did) expire.
- Identification of the certificate that is expiring is built into the notification itself. For an example, please see [Section 2.2.3](#).

2.1.4.8. The "trust-anchor-cert-grouping" Grouping

This section presents a tree diagram [RFC8340] illustrating the "trust-anchor-cert-grouping" grouping. This tree diagram does not expand the internally used "grouping" statement(s):

```
grouping trust-anchor-cert-grouping:
  +-- cert-data?          trust-anchor-cert-cms
  +---u certificate-expiration-grouping
```

Comments:

- For the referenced "grouping" statement(s):
 - The "certificate-expiration-grouping" grouping is discussed in [Section 2.1.4.7](#).
- The "cert-data" node contains a chain of one or more certificates containing at most one self-signed certificate (the "root" certificate), encoded using a "signed-data-cms" typedef discussed in [Section 2.1.3](#).

2.1.4.9. The "end-entity-cert-grouping" Grouping

This section presents a tree diagram [RFC8340] illustrating the "end-entity-cert-grouping" grouping. This tree diagram does not expand the internally used "grouping" statement(s):

```
grouping end-entity-cert-grouping:
  +-- cert-data?                               end-entity-cert-cms
  +---u certificate-expiration-grouping
```

Comments:

- For the referenced "grouping" statement(s):
 - The "certificate-expiration-grouping" grouping is discussed in [Section 2.1.4.7](#).
- The "cert-data" node contains a chain of one or more certificates containing at most one certificate that is not self-signed and does not have Basic constraint "CA true" (where "CA" means Certification Authority), encoded using a "signed-data-cms" typedef discussed in [Section 2.1.3](#).

2.1.4.10. The "generate-csr-grouping" Grouping

This section presents a tree diagram [RFC8340] illustrating the "generate-csr-grouping" grouping:

```
grouping generate-csr-grouping:
  +---x generate-csr {csr-generation}?
  +---w input
  |   +---w csr-format      identityref
  |   +---w csr-info        csr-info
  +--ro output
  +--ro (csr-type)
  +--:(p10-csr)
  +--ro p10-csr?      p10-csr
```

Comments:

- This grouping's only purpose is to define the "generate-csr" action statement, used by the groupings defined in [Sections 2.1.4.11](#) and [2.1.4.12](#).
- This action takes two input parameters: a "csr-info" parameter, for what content should be in the certificate, and a "csr-format" parameter, for what CSR format to return. The action returns the CSR in the specified format. Both the "csr-info" and "csr" types are discussed in [Section 2.1.3](#).
- For an example, please see [Section 2.2.2](#).

2.1.4.11. The "asymmetric-key-pair-with-cert-grouping" Grouping

This section presents a tree diagram [RFC8340] illustrating the "asymmetric-key-pair-with-cert-grouping" grouping. This tree diagram does not expand the internally used "grouping" statement(s):

```

grouping asymmetric-key-pair-with-cert-grouping:
  +---u asymmetric-key-pair-grouping
  +---u end-entity-cert-grouping
  +---u generate-csr-grouping

```

Comments:

- This grouping defines an asymmetric key with at most one associated certificate, a commonly needed combination in protocol models.
- For the referenced "grouping" statement(s):
 - The "asymmetric-key-pair-grouping" grouping is discussed in [Section 2.1.4.6](#).
 - The "end-entity-cert-grouping" grouping is discussed in [Section 2.1.4.9](#).
 - The "generate-csr-grouping" grouping is discussed in [Section 2.1.4.10](#).

2.1.4.12. The "asymmetric-key-pair-with-certs-grouping" Grouping

This section presents a tree diagram [RFC8340] illustrating the "asymmetric-key-pair-with-certs-grouping" grouping. This tree diagram does not expand the internally used "grouping" statement(s):

```

grouping asymmetric-key-pair-with-certs-grouping:
  +---u asymmetric-key-pair-grouping
  +-- certificates
  |   +-- certificate* [name]
  |       +-- name                string
  |       +---u end-entity-cert-grouping
  +---u generate-csr-grouping

```

Comments:

- This grouping defines an asymmetric key with one or more associated certificates, a commonly needed combination in configuration models.
- For the referenced "grouping" statement(s):
 - The "asymmetric-key-pair-grouping" grouping is discussed in [Section 2.1.4.6](#).
 - The "end-entity-cert-grouping" grouping is discussed in [Section 2.1.4.9](#).
 - The "generate-csr-grouping" grouping is discussed in [Section 2.1.4.10](#).

2.1.5. Protocol-Accessible Nodes

The "ietf-crypto-types" module does not contain any protocol-accessible nodes, but the module needs to be "implemented", as described in [Section 5.6.5](#) of [RFC7950], in order for the identities in [Section 2.1.2](#) to be defined.

2.2. Example Usage

2.2.1. The "symmetric-key-grouping", "asymmetric-key-pair-with-certs-grouping", and "password-grouping" Groupings

The following non-normative module is constructed in order to illustrate the use of the "symmetric-key-grouping" (Section 2.1.4.3), the "asymmetric-key-pair-with-certs-grouping" (Section 2.1.4.12), and the "password-grouping" (Section 2.1.4.2) "grouping" statements.

Notably, this example module and associated configuration data illustrates that a hidden private key (ex-hidden-asymmetric-key) has been used to encrypt a symmetric key (ex-encrypted-one-symmetric-based-symmetric-key) that has been used to encrypt another private key (ex-encrypted-rsa-based-asymmetric-key). Additionally, the symmetric key is also used to encrypt a password (ex-encrypted-password).

2.2.1.1. Example Module

```
module ex-crypto-types-usage {
  yang-version 1.1;
  namespace "https://example.com/ns/example-crypto-types-usage";
  prefix ectu;

  import ietf-crypto-types {
    prefix ct;
    reference
      "RFC 9640: YANG Data Types and Groupings for Cryptography";
  }

  organization
    "Example Corporation";
  contact
    "YANG Designer <mailto:yang.designer@example.com>";

  description
    "This example module illustrates the 'symmetric-key-grouping'
    and 'asymmetric-key-grouping' groupings defined in the
    'ietf-crypto-types' module defined in RFC 9640.";

  revision 2024-03-16 {
    description
      "Initial version.";
    reference
      "RFC 9640: YANG Data Types and Groupings for Cryptography";
  }

  container symmetric-keys {
    description
      "A container of symmetric keys.";
    list symmetric-key {
      key "name";
      description
        "A symmetric key.";
      leaf name {
```



```

|         +--rw encrypted-by
|         |   +--rw (encrypted-by)
|         |   |   +--:(symmetric-key-ref)
|         |   |   |   +--rw symmetric-key-ref?   leafref
|         |   |   +--:(asymmetric-key-ref)
|         |   |   |   +--rw asymmetric-key-ref?  leafref
|         |   +--rw encrypted-value-format   identityref
|         |   +--rw encrypted-value         binary
+--rw asymmetric-keys
|   +--rw asymmetric-key* [name]
|   |   +--rw name                               string
|   |   +--rw public-key-format?                identityref
|   |   +--rw public-key?                      binary
|   |   +--rw private-key-format?              identityref
|   |   +--rw (private-key-type)
|   |   |   +--:(cleartext-private-key) {cleartext-private-keys}?
|   |   |   |   +--rw cleartext-private-key?   binary
|   |   |   +--:(hidden-private-key) {hidden-private-keys}?
|   |   |   |   +--rw hidden-private-key?     empty
|   |   |   +--:(encrypted-private-key) {encrypted-private-keys}?
|   |   |   |   +--rw encrypted-private-key
|   |   |   |   |   +--rw encrypted-by
|   |   |   |   |   |   +--rw (encrypted-by)
|   |   |   |   |   |   |   +--:(symmetric-key-ref)
|   |   |   |   |   |   |   |   +--rw symmetric-key-ref?   leafref
|   |   |   |   |   |   |   +--:(asymmetric-key-ref)
|   |   |   |   |   |   |   |   +--rw asymmetric-key-ref?  leafref
|   |   |   |   |   +--rw encrypted-value-format   identityref
|   |   |   |   +--rw encrypted-value         binary
+--rw certificates
|   +--rw certificate* [name]
|   |   +--rw name                               string
|   |   +--rw cert-data                         end-entity-cert-cms
|   |   +---n certificate-expiration
|   |   |   {certificate-expiration-notification}?
|   |   |   +-- expiration-date   yang:date-and-time
+---x generate-csr {csr-generation}?
|   +---w input
|   |   +---w csr-format   identityref
|   |   +---w csr-info     csr-info
+---ro output
|   +---ro (csr-type)
|   |   +---:(p10-csr)
|   |   +---ro p10-csr?  p10-csr
+--rw passwords
|   +--rw password* [name]
|   |   +--rw name                               string
|   |   +--rw (password-type)
|   |   |   +--:(cleartext-password) {cleartext-passwords}?
|   |   |   |   +--rw cleartext-password?   string
|   |   |   +--:(encrypted-password) {encrypted-passwords}?
|   |   |   |   +--rw encrypted-password
|   |   |   |   |   +--rw encrypted-by
|   |   |   |   |   |   +--rw (encrypted-by)
|   |   |   |   |   |   |   +--:(symmetric-key-ref)
|   |   |   |   |   |   |   |   +--rw symmetric-key-ref?   leafref
|   |   |   |   |   |   |   +--:(asymmetric-key-ref)
|   |   |   |   |   |   |   |   +--rw asymmetric-key-ref?  leafref

```

+-rw encrypted-value-format	identityref
+-rw encrypted-value	binary

2.2.1.3. Usage Example for the Example Module

Finally, the following example illustrates various symmetric and asymmetric keys as they might appear in configuration.

```

===== NOTE: '\ ' line wrapping per RFC 8792 =====
<symmetric-keys
  xmlns="https://example.com/ns/example-crypto-types-usage"
  xmlns:ct="urn:ietf:params:xml:ns:yang:ietf-crypto-types">
  <symmetric-key>
    <name>ex-hidden-symmetric-key</name>
    <hidden-symmetric-key/>
  </symmetric-key>
  <symmetric-key>
    <name>ex-octet-string-based-symmetric-key</name>
    <key-format>ct:octet-string-key-format</key-format>
    <cleartext-symmetric-key>BASE64VALUE=</cleartext-symmetric-key>
  </symmetric-key>
  <symmetric-key>
    <name>ex-one-symmetric-based-symmetric-key</name>
    <key-format>ct:one-symmetric-key-format</key-format>
    <cleartext-symmetric-key>BASE64VALUE=</cleartext-symmetric-key>
  </symmetric-key>
  <symmetric-key>
    <name>ex-encrypted-one-symmetric-based-symmetric-key</name>
    <key-format>ct:one-symmetric-key-format</key-format>
    <encrypted-symmetric-key>
      <encrypted-by>
        <asymmetric-key-ref>ex-hidden-asymmetric-key</asymmetric-key\
- ref>
      </encrypted-by>
      <encrypted-value-format>ct:cms-enveloped-data-format</encrypte\
d-value-format>
      <encrypted-value>BASE64VALUE=</encrypted-value>
    </encrypted-symmetric-key>
  </symmetric-key>
</symmetric-keys>

<asymmetric-keys
  xmlns="https://example.com/ns/example-crypto-types-usage"
  xmlns:ct="urn:ietf:params:xml:ns:yang:ietf-crypto-types">
  <asymmetric-key>
    <name>ex-hidden-asymmetric-key</name>
    <public-key-format>ct:subject-public-key-info-format</public-key\
-format>
    <public-key>BASE64VALUE=</public-key>
    <hidden-private-key/>
    <certificates>
      <certificate>
        <name>ex-hidden-asymmetric-key-cert</name>
        <cert-data>BASE64VALUE=</cert-data>
      </certificate>

```

```

    </certificates>
  </asymmetric-key>
  <asymmetric-key>
    <name>ex-rsa-based-asymmetric-key</name>
    <public-key-format>ct:subject-public-key-info-format</public-key\
-format>
    <public-key>BASE64VALUE=</public-key>
    <private-key-format>ct:rsa-private-key-format</private-key-forma\
t>
    <cleartext-private-key>BASE64VALUE=</cleartext-private-key>
    <certificates>
      <certificate>
        <name>ex-cert</name>
        <cert-data>BASE64VALUE=</cert-data>
      </certificate>
    </certificates>
  </asymmetric-key>
  <asymmetric-key>
    <name>ex-one-asymmetric-based-asymmetric-key</name>
    <public-key-format>ct:subject-public-key-info-format</public-key\
-format>
    <public-key>BASE64VALUE=</public-key>
    <private-key-format>ct:one-asymmetric-key-format</private-key-fo\
rmat>
    <cleartext-private-key>BASE64VALUE=</cleartext-private-key>
  </asymmetric-key>
  <asymmetric-key>
    <name>ex-encrypted-rsa-based-asymmetric-key</name>
    <public-key-format>ct:subject-public-key-info-format</public-key\
-format>
    <public-key>BASE64VALUE=</public-key>
    <private-key-format>ct:rsa-private-key-format</private-key-forma\
t>
    <encrypted-private-key>
      <encrypted-by>
        <symmetric-key-ref>ex-encrypted-one-symmetric-based-symmetri\
c-key</symmetric-key-ref>
      </encrypted-by>
      <encrypted-value-format>ct:cms-encrypted-data-format</encrypte\
d-value-format>
      <encrypted-value>BASE64VALUE=</encrypted-value>
    </encrypted-private-key>
  </asymmetric-key>
</asymmetric-keys>

<passwords
  xmlns="https://example.com/ns/example-crypto-types-usage"
  xmlns:ct="urn:ietf:params:xml:ns:yang:ietf-crypto-types">
  <password>
    <name>ex-cleartext-password</name>
    <cleartext-password>super-secret</cleartext-password>
  </password>
  <password>
    <name>ex-encrypted-password</name>
    <encrypted-password>
      <encrypted-by>
        <symmetric-key-ref>ex-encrypted-one-symmetric-based-symmetri\
c-key</symmetric-key-ref>

```

```

    </encrypted-by>
    <encrypted-value-format>ct:cms-encrypted-data-format</encrypte\
d-value-format>
    <encrypted-value>BASE64VALUE=</encrypted-value>
  </encrypted-password>
</password>
</passwords>

```

2.2.2. The "generate-csr" Action

The following example illustrates the "generate-csr" action, discussed in [Section 2.1.4.10](#), with the NETCONF protocol.

REQUEST

```

<rpc message-id="101"
  xmlns="urn:ietf:params:xml:ns:netconf:base:1.0"
  xmlns:ct="urn:ietf:params:xml:ns:yang:ietf-crypto-types">
  <action xmlns="urn:ietf:params:xml:ns:yang:1">
    <asymmetric-keys
      xmlns="https://example.com/ns/example-crypto-types-usage">
      <asymmetric-key>
        <name>ex-hidden-asymmetric-key</name>
        <generate-csr>
          <csr-format>ct:p10-csr-format</csr-format>
          <csr-info>BASE64VALUE=</csr-info>
        </generate-csr>
      </asymmetric-key>
    </asymmetric-keys>
  </action>
</rpc>

```

RESPONSE

```

===== NOTE: '\' line wrapping per RFC 8792 =====

<rpc-reply message-id="101"
  xmlns="urn:ietf:params:xml:ns:netconf:base:1.0">
  <p10-csr xmlns="https://example.com/ns/example-crypto-types-usage"\
>BASE64VALUE=</p10-csr>
</rpc-reply>

```

2.2.3. The "certificate-expiration" Notification

The following example illustrates the "certificate-expiration" notification, discussed in [Section 2.1.4.7](#), with the NETCONF protocol.

```

===== NOTE: '\ ' line wrapping per RFC 8792 =====

<notification
  xmlns="urn:ietf:params:xml:ns:netconf:notification:1.0">
  <eventTime>2018-05-25T00:01:00Z</eventTime>
  <asymmetric-keys xmlns="https://example.com/ns/example-crypto-type\
s-usage">
    <asymmetric-key>
      <name>ex-hidden-asymmetric-key</name>
      <certificates>
        <certificate>
          <name>ex-hidden-asymmetric-key-cert</name>
          <certificate-expiration>
            <expiration-date>2018-08-05T14:18:53-05:00</expiration-d\
ate>
              </certificate-expiration>
            </certificate>
          </certificates>
        </asymmetric-key>
      </asymmetric-keys>
    </notification>

```

2.3. YANG Module

This module has normative references to [\[RFC2119\]](#), [\[RFC2986\]](#), [\[RFC4253\]](#), [\[RFC5280\]](#), [\[RFC5652\]](#), [\[RFC5915\]](#), [\[RFC5958\]](#), [\[RFC6031\]](#), [\[RFC6960\]](#), [\[RFC6991\]](#), [\[RFC7093\]](#), [\[RFC8017\]](#), [\[RFC8174\]](#), [\[RFC8341\]](#), and [\[ITU.X690.2021\]](#).

```

<CODE BEGINS> file "ietf-crypto-types@2024-03-16.yang"

module ietf-crypto-types {
  yang-version 1.1;
  namespace "urn:ietf:params:xml:ns:yang:ietf-crypto-types";
  prefix ct;

  import ietf-yang-types {
    prefix yang;
    reference
      "RFC 6991: Common YANG Data Types";
  }

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

  organization
    "IETF NETCONF (Network Configuration) Working Group";

  contact
    "WG Web:  https://datatracker.ietf.org/wg/netconf
    WG List:  NETCONF WG list <mailto:netconf@ietf.org>
    Author:   Kent Watsen <mailto:kent+ietf@watsen.net>";

```

```
description
  "This module defines common YANG types for cryptographic
  applications.

  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.

  Copyright (c) 2024 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 Revised
  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 9640
  (https://www.rfc-editor.org/info/rfc9640); see the RFC
  itself for full legal notices."

revision 2024-03-16 {
  description
    "Initial version.";
  reference
    "RFC 9640: YANG Data Types and Groupings for Cryptography";
}

/*****
/* Features */
*****/

feature one-symmetric-key-format {
  description
    "Indicates that the server supports the
    'one-symmetric-key-format' identity.";
}

feature one-asymmetric-key-format {
  description
    "Indicates that the server supports the
    'one-asymmetric-key-format' identity.";
}

feature symmetrically-encrypted-value-format {
  description
    "Indicates that the server supports the
    'symmetrically-encrypted-value-format' identity.";
}

feature asymmetrically-encrypted-value-format {
  description
    "Indicates that the server supports the
```

```
    'asymmetrically-encrypted-value-format' identity.";
  }

feature cms-enveloped-data-format {
  description
    "Indicates that the server supports the
    'cms-enveloped-data-format' identity.";
}

feature cms-encrypted-data-format {
  description
    "Indicates that the server supports the
    'cms-encrypted-data-format' identity.";
}

feature p10-csr-format {
  description
    "Indicates that the server implements support
    for generating P10-based CSRs, as defined
    in RFC 2986.";
  reference
    "RFC 2986: PKCS #10: Certification Request Syntax
    Specification Version 1.7";
}

feature csr-generation {
  description
    "Indicates that the server implements the
    'generate-csr' action.";
}

feature certificate-expiration-notification {
  description
    "Indicates that the server implements the
    'certificate-expiration' notification.";
}

feature cleartext-passwords {
  description
    "Indicates that the server supports cleartext
    passwords.";
}

feature encrypted-passwords {
  description
    "Indicates that the server supports password
    encryption.";
}

feature cleartext-symmetric-keys {
  description
    "Indicates that the server supports cleartext
    symmetric keys.";
}

feature hidden-symmetric-keys {
  description
    "Indicates that the server supports hidden keys.";
```

```
}

feature encrypted-symmetric-keys {
  description
    "Indicates that the server supports encryption
    of symmetric keys.";
}

feature cleartext-private-keys {
  description
    "Indicates that the server supports cleartext
    private keys.";
}

feature hidden-private-keys {
  description
    "Indicates that the server supports hidden keys.";
}

feature encrypted-private-keys {
  description
    "Indicates that the server supports encryption
    of private keys.";
}

/*****
/* Base Identities for Key Format Structures */
*****/

identity symmetric-key-format {
  description
    "Base key-format identity for symmetric keys.";
}

identity public-key-format {
  description
    "Base key-format identity for public keys.";
}

identity private-key-format {
  description
    "Base key-format identity for private keys.";
}

/*****
/* Identities for Private Key Format Structures */
*****/

identity rsa-private-key-format {
  base private-key-format;
  description
    "Indicates that the private key value is encoded as
    an RSAPrivateKey (from RFC 8017), encoded using ASN.1
    distinguished encoding rules (DER), as specified in
    ITU-T X.690.";
  reference
    "RFC 8017:
    PKCS #1: RSA Cryptography Specifications Version 2.2
```



```

        ITU-T X.690:
        Information technology - ASN.1 encoding rules:
        Specification of Basic Encoding Rules (BER),
        Canonical Encoding Rules (CER) and Distinguished
        Encoding Rules (DER) 02/2021";
    }

identity ec-private-key-format {
    base private-key-format;
    description
        "Indicates that the private key value is encoded as
        an ECPrivateKey (from RFC 5915), encoded using ASN.1
        distinguished encoding rules (DER), as specified in
        ITU-T X.690.";
    reference
        "RFC 5915:
        Elliptic Curve Private Key Structure
        ITU-T X.690:
        Information technology - ASN.1 encoding rules:
        Specification of Basic Encoding Rules (BER),
        Canonical Encoding Rules (CER) and Distinguished
        Encoding Rules (DER) 02/2021";
}

identity one-asymmetric-key-format {
    if-feature "one-asymmetric-key-format";
    base private-key-format;
    description
        "Indicates that the private key value is a
        Cryptographic Message Syntax (CMS) OneAsymmetricKey
        structure, as defined in RFC 5958, encoded using
        ASN.1 distinguished encoding rules (DER), as
        specified in ITU-T X.690.";
    reference
        "RFC 5958:
        Asymmetric Key Packages
        ITU-T X.690:
        Information technology - ASN.1 encoding rules:
        Specification of Basic Encoding Rules (BER),
        Canonical Encoding Rules (CER) and Distinguished
        Encoding Rules (DER) 02/2021";
}

/*****
/*  Identities for Public Key Format Structures  */
*****/

identity ssh-public-key-format {
    base public-key-format;
    description
        "Indicates that the public key value is a Secure Shell (SSH)
        public key, as specified in RFC 4253, Section 6.6, i.e.:

        string    certificate or public key format
                  identifier
        byte[n]   key/certificate data.";
    reference
        "RFC 4253: The Secure Shell (SSH) Transport Layer Protocol";
}

```

```

}

identity subject-public-key-info-format {
  base public-key-format;
  description
    "Indicates that the public key value is a SubjectPublicKeyInfo
     structure, as described in RFC 5280, encoded using ASN.1
     distinguished encoding rules (DER), as specified in
     ITU-T X.690.";
  reference
    "RFC 5280:
     Internet X.509 Public Key Infrastructure Certificate
     and Certificate Revocation List (CRL) Profile
     ITU-T X.690:
     Information technology - ASN.1 encoding rules:
     Specification of Basic Encoding Rules (BER),
     Canonical Encoding Rules (CER) and Distinguished
     Encoding Rules (DER) 02/2021";
}

/*****
/*  Identities for Symmetric Key Format Structures  */
*****/

identity octet-string-key-format {
  base symmetric-key-format;
  description
    "Indicates that the key is encoded as a raw octet string.
     The length of the octet string MUST be appropriate for
     the associated algorithm's block size.

     The identity of the associated algorithm is outside the
     scope of this specification. This is also true when
     the octet string has been encrypted.";
}

identity one-symmetric-key-format {
  if-feature "one-symmetric-key-format";
  base symmetric-key-format;
  description
    "Indicates that the private key value is a CMS
     OneSymmetricKey structure, as defined in RFC 6031,
     encoded using ASN.1 distinguished encoding rules
     (DER), as specified in ITU-T X.690.";
  reference
    "RFC 6031:
     Cryptographic Message Syntax (CMS)
     Symmetric Key Package Content Type
     ITU-T X.690:
     Information technology - ASN.1 encoding rules:
     Specification of Basic Encoding Rules (BER),
     Canonical Encoding Rules (CER) and Distinguished
     Encoding Rules (DER) 02/2021";
}

/*****
/*  Identities for Encrypted Value Structures  */
*****/

```

```
identity encrypted-value-format {
  description
    "Base format identity for encrypted values.";
}

identity symmetrically-encrypted-value-format {
  if-feature "symmetrically-encrypted-value-format";
  base encrypted-value-format;
  description
    "Base format identity for symmetrically encrypted
    values.";
}

identity asymmetrically-encrypted-value-format {
  if-feature "asymmetrically-encrypted-value-format";
  base encrypted-value-format;
  description
    "Base format identity for asymmetrically encrypted
    values.";
}

identity cms-encrypted-data-format {
  if-feature "cms-encrypted-data-format";
  base symmetrically-encrypted-value-format;
  description
    "Indicates that the encrypted value conforms to
    the 'encrypted-data-cms' type with the constraint
    that the 'unprotectedAttrs' value is not set.";
  reference
    "RFC 5652:
    Cryptographic Message Syntax (CMS)
    ITU-T X.690:
    Information technology - ASN.1 encoding rules:
    Specification of Basic Encoding Rules (BER),
    Canonical Encoding Rules (CER) and Distinguished
    Encoding Rules (DER) 02/2021";
}

identity cms-enveloped-data-format {
  if-feature "cms-enveloped-data-format";
  base asymmetrically-encrypted-value-format;
  description
    "Indicates that the encrypted value conforms to the
    'enveloped-data-cms' type with the following constraints:

    The EnvelopedData structure MUST have exactly one
    'RecipientInfo'.

    If the asymmetric key supports public key cryptography
    (e.g., RSA), then the 'RecipientInfo' must be a
    'KeyTransRecipientInfo' with the 'RecipientIdentifier'
    using a 'subjectKeyIdentifier' with the value set using
    'method 1' in RFC 7093 over the recipient's public key.

    Otherwise, if the asymmetric key supports key agreement
    (e.g., Elliptic Curve Cryptography (ECC)), then the
    'RecipientInfo' must be a 'KeyAgreeRecipientInfo'. The
```

```

    'OriginatorIdentifierOrKey' value must use the
    'OriginatorPublicKey' alternative. The
    'UserKeyingMaterial' value must not be present. There
    must be exactly one 'RecipientEncryptedKeys' value
    having the 'KeyAgreeRecipientIdentifier' set to 'rKeyId'
    with the value set using 'method 1' in RFC 7093 over the
    recipient's public key.";
reference
  "RFC 5652:
    Cryptographic Message Syntax (CMS)
  RFC 7093:
    Additional Methods for Generating Key
    Identifiers Values
  ITU-T X.690:
    Information technology - ASN.1 encoding rules:
    Specification of Basic Encoding Rules (BER),
    Canonical Encoding Rules (CER) and Distinguished
    Encoding Rules (DER) 02/2021";
}

/*****
/* Identities for Certificate Signing Request Formats */
*****/

identity csr-format {
  description
    "A base identity for the certificate signing request
    formats. Additional derived identities MAY be defined
    by future efforts.";
}

identity p10-csr-format {
  if-feature "p10-csr-format";
  base csr-format;
  description
    "Indicates the CertificationRequest structure
    defined in RFC 2986.";
  reference
    "RFC 2986: PKCS #10: Certification Request Syntax
    Specification Version 1.7";
}

/*****
/* Typedefs for ASN.1 structures from RFC 2986 */
*****/

typedef csr-info {
  type binary;
  description
    "A CertificationRequestInfo structure, as defined in
    RFC 2986, encoded using ASN.1 distinguished encoding
    rules (DER), as specified in ITU-T X.690.";
  reference
    "RFC 2986:
      PKCS #10: Certification Request Syntax
      Specification Version 1.7
    ITU-T X.690:

```

```

        Information technology - ASN.1 encoding rules:
        Specification of Basic Encoding Rules (BER),
        Canonical Encoding Rules (CER) and Distinguished
        Encoding Rules (DER) 02/2021";
    }

typedef p10-csr {
    type binary;
    description
        "A CertificationRequest structure, as specified in
        RFC 2986, encoded using ASN.1 distinguished encoding
        rules (DER), as specified in ITU-T X.690.";
    reference
        "RFC 2986:
        PKCS #10: Certification Request Syntax Specification
        Version 1.7
        ITU-T X.690:
        Information technology - ASN.1 encoding rules:
        Specification of Basic Encoding Rules (BER),
        Canonical Encoding Rules (CER) and Distinguished
        Encoding Rules (DER) 02/2021";
}

/*****
/*  Typedefs for ASN.1 structures from RFC 5280  */
*****/

typedef x509 {
    type binary;
    description
        "A Certificate structure, as specified in RFC 5280,
        encoded using ASN.1 distinguished encoding rules (DER),
        as specified in ITU-T X.690.";
    reference
        "RFC 5280:
        Internet X.509 Public Key Infrastructure Certificate
        and Certificate Revocation List (CRL) Profile
        ITU-T X.690:
        Information technology - ASN.1 encoding rules:
        Specification of Basic Encoding Rules (BER),
        Canonical Encoding Rules (CER) and Distinguished
        Encoding Rules (DER) 02/2021";
}

typedef crl {
    type binary;
    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 5280:
        Internet X.509 Public Key Infrastructure Certificate
        and Certificate Revocation List (CRL) Profile
        ITU-T X.690:
        Information technology - ASN.1 encoding rules:
        Specification of Basic Encoding Rules (BER),
        Canonical Encoding Rules (CER) and Distinguished

```

```
        Encoding Rules (DER) 02/2021";
    }

/*****
/* Typedefs for ASN.1 structures from RFC 6960 */
*****/

typedef oscp-request {
    type binary;
    description
        "A OCSPRequest structure, as specified in RFC 6960,
        encoded using ASN.1 distinguished encoding rules
        (DER), as specified in ITU-T X.690.";
    reference
        "RFC 6960:
        X.509 Internet Public Key Infrastructure Online
        Certificate Status Protocol - OCSP
        ITU-T X.690:
        Information technology - ASN.1 encoding rules:
        Specification of Basic Encoding Rules (BER),
        Canonical Encoding Rules (CER) and Distinguished
        Encoding Rules (DER) 02/2021";
}

typedef oscp-response {
    type binary;
    description
        "A OCSPResponse structure, as specified in RFC 6960,
        encoded using ASN.1 distinguished encoding rules
        (DER), as specified in ITU-T X.690.";
    reference
        "RFC 6960:
        X.509 Internet Public Key Infrastructure Online
        Certificate Status Protocol - OCSP
        ITU-T X.690:
        Information technology - ASN.1 encoding rules:
        Specification of Basic Encoding Rules (BER),
        Canonical Encoding Rules (CER) and Distinguished
        Encoding Rules (DER) 02/2021";
}

/*****
/* Typedefs for ASN.1 structures from 5652 */
*****/

typedef cms {
    type binary;
    description
        "A ContentInfo structure, as specified in RFC 5652,
        encoded using ASN.1 distinguished encoding rules (DER),
        as specified in ITU-T X.690.";
    reference
        "RFC 5652:
        Cryptographic Message Syntax (CMS)
        ITU-T X.690:
        Information technology - ASN.1 encoding rules:
        Specification of Basic Encoding Rules (BER),
        Canonical Encoding Rules (CER) and Distinguished
```

```
        Encoding Rules (DER) 02/2021";
    }

typedef data-content-cms {
    type cms;
    description
        "A CMS structure whose top-most content type MUST be the
        data content type, as described in Section 4 of RFC 5652.";
    reference
        "RFC 5652: Cryptographic Message Syntax (CMS)";
}

typedef signed-data-cms {
    type cms;
    description
        "A CMS structure whose top-most content type MUST be the
        signed-data content type, as described in Section 5 of
        RFC 5652.";
    reference
        "RFC 5652: Cryptographic Message Syntax (CMS)";
}

typedef enveloped-data-cms {
    type cms;
    description
        "A CMS structure whose top-most content type MUST be the
        enveloped-data content type, as described in Section 6
        of RFC 5652.";
    reference
        "RFC 5652: Cryptographic Message Syntax (CMS)";
}

typedef digested-data-cms {
    type cms;
    description
        "A CMS structure whose top-most content type MUST be the
        digested-data content type, as described in Section 7
        of RFC 5652.";
    reference
        "RFC 5652: Cryptographic Message Syntax (CMS)";
}

typedef encrypted-data-cms {
    type cms;
    description
        "A CMS structure whose top-most content type MUST be the
        encrypted-data content type, as described in Section 8
        of RFC 5652.";
    reference
        "RFC 5652: Cryptographic Message Syntax (CMS)";
}

typedef authenticated-data-cms {
    type cms;
    description
        "A CMS structure whose top-most content type MUST be the
        authenticated-data content type, as described in Section 9
        of RFC 5652.";
```

```

    reference
      "RFC 5652: Cryptographic Message Syntax (CMS)";
  }

/*****
/*  Typedefs for ASN.1 structures related to RFC 5280  */
*****/

typedef trust-anchor-cert-x509 {
  type x509;
  description
    "A Certificate structure that MUST encode a self-signed
    root certificate.";
}

typedef end-entity-cert-x509 {
  type x509;
  description
    "A Certificate structure that MUST encode a certificate
    that is neither self-signed nor has Basic constraint
    CA true.";
}

/*****
/*  Typedefs for ASN.1 structures related to RFC 5652  */
*****/

typedef trust-anchor-cert-cms {
  type signed-data-cms;
  description
    "A CMS SignedData structure that MUST contain the chain of
    X.509 certificates needed to authenticate the certificate
    presented by a client or end entity.

    The CMS MUST contain only a single chain of certificates.
    The client or end-entity certificate MUST only authenticate
    to the last intermediate CA certificate listed in the chain.

    In all cases, the chain MUST include a self-signed root
    certificate. In the case where the root certificate is
    itself the issuer of the client or end-entity certificate,
    only one certificate is present.

    This CMS structure MAY (as applicable where this type is
    used) also contain suitably fresh (as defined by local
    policy) revocation objects with which the device can
    verify the revocation status of the certificates.

    This CMS encodes the degenerate form of the SignedData
    structure (RFC 5652, Section 5.2) that is commonly used
    to disseminate X.509 certificates and revocation objects
    (RFC 5280).";
  reference
    "RFC 5280:
      Internet X.509 Public Key Infrastructure Certificate
      and Certificate Revocation List (CRL) Profile
    RFC 5652:
      Cryptographic Message Syntax (CMS)";
}

```



```

}

typedef end-entity-cert-cms {
  type signed-data-cms;
  description
    "A CMS SignedData structure that MUST contain the end-entity
    certificate itself and MAY contain any number
    of intermediate certificates leading up to a trust
    anchor certificate. The trust anchor certificate
    MAY be included as well.

    The CMS MUST contain a single end-entity certificate.
    The CMS MUST NOT contain any spurious certificates.

    This CMS structure MAY (as applicable where this type is
    used) also contain suitably fresh (as defined by local
    policy) revocation objects with which the device can
    verify the revocation status of the certificates.

    This CMS encodes the degenerate form of the SignedData
    structure (RFC 5652, Section 5.2) that is commonly
    used to disseminate X.509 certificates and revocation
    objects (RFC 5280).";

  reference
    "RFC 5280:
    Internet X.509 Public Key Infrastructure Certificate
    and Certificate Revocation List (CRL) Profile
    RFC 5652:
    Cryptographic Message Syntax (CMS)";
}

/*****/
/* Groupings */
/*****/

grouping encrypted-value-grouping {
  description
    "A reusable grouping for a value that has been encrypted by
    a referenced symmetric or asymmetric key.";
  container encrypted-by {
    nacm:default-deny-write;
    description
      "An empty container enabling a reference to the key that
      encrypted the value to be augmented in. The referenced
      key MUST be a symmetric key or an asymmetric key.

      A symmetric key MUST be referenced via a leaf node called
      'symmetric-key-ref'. An asymmetric key MUST be referenced
      via a leaf node called 'asymmetric-key-ref'.

      The leaf nodes MUST be direct descendants in the data tree
      and MAY be direct descendants in the schema tree (e.g.,
      'choice'/'case' statements are allowed but not a
      container).";
  }
  leaf encrypted-value-format {
    type identityref {

```

```

    base encrypted-value-format;
  }
  mandatory true;
  description
    "Identifies the format of the 'encrypted-value' leaf.

    If 'encrypted-by' points to a symmetric key, then an
    identity based on 'symmetrically-encrypted-value-format'
    MUST be set (e.g., 'cms-encrypted-data-format').

    If 'encrypted-by' points to an asymmetric key, then an
    identity based on 'asymmetrically-encrypted-value-format'
    MUST be set (e.g., 'cms-enveloped-data-format').";
}
leaf encrypted-value {
  nacm:default-deny-write;
  type binary;
  must '../encrypted-by';
  mandatory true;
  description
    "The value, encrypted using the referenced symmetric
    or asymmetric key. The value MUST be encoded using
    the format associated with the 'encrypted-value-format'
    leaf.";
}
}

grouping password-grouping {
  description
    "A password used for authenticating to a remote system.

    The 'ianach:crypt-hash' typedef from RFC 7317 should be
    used instead when needing a password to authenticate a
    local account.";
  choice password-type {
    nacm:default-deny-write;
    mandatory true;
    description
      "Choice between password types.";
    case cleartext-password {
      if-feature "cleartext-passwords";
      leaf cleartext-password {
        nacm:default-deny-all;
        type string;
        description
          "The cleartext value of the password.";
      }
    }
    case encrypted-password {
      if-feature "encrypted-passwords";
      container encrypted-password {
        description
          "A container for the encrypted password value.";
        uses encrypted-value-grouping;
      }
    }
  }
}
}

```

```
grouping symmetric-key-grouping {
  description
    "A symmetric key.";
  leaf key-format {
    nacm:default-deny-write;
    type identityref {
      base symmetric-key-format;
    }
    description
      "Identifies the symmetric key's format. Implementations
      SHOULD ensure that the incoming symmetric key value is
      encoded in the specified format.

      For encrypted keys, the value is the decrypted key's
      format (i.e., the 'encrypted-value-format' conveys the
      encrypted key's format).";
  }
  choice key-type {
    nacm:default-deny-write;
    mandatory true;
    description
      "Choice between key types.";
    case cleartext-symmetric-key {
      leaf cleartext-symmetric-key {
        if-feature "cleartext-symmetric-keys";
        nacm:default-deny-all;
        type binary;
        must '../key-format';
        description
          "The binary value of the key. The interpretation of
          the value is defined by the 'key-format' field.";
      }
    }
    case hidden-symmetric-key {
      if-feature "hidden-symmetric-keys";
      leaf hidden-symmetric-key {
        type empty;
        must 'not(..key-format)';
        description
          "A hidden key is not exportable and not extractable;
          therefore, it is of type 'empty' as its value is
          inaccessible via management interfaces. Though hidden
          to users, such keys are not hidden to the server and
          may be referenced by configuration to indicate which
          key a server should use for a cryptographic operation.
          How such keys are created is outside the scope of this
          module.";
      }
    }
    case encrypted-symmetric-key {
      if-feature "encrypted-symmetric-keys";
      container encrypted-symmetric-key {
        must '../key-format';
        description
          "A container for the encrypted symmetric key value.
          The interpretation of the 'encrypted-value' node
          is via the 'key-format' node";
      }
    }
  }
}
```

```

        uses encrypted-value-grouping;
    }
}
}

grouping public-key-grouping {
  description
    "A public key.";
  leaf public-key-format {
    nacm:default-deny-write;
    type identityref {
      base public-key-format;
    }
    mandatory true;
    description
      "Identifies the public key's format. Implementations SHOULD
      ensure that the incoming public key value is encoded in the
      specified format.";
  }
  leaf public-key {
    nacm:default-deny-write;
    type binary;
    mandatory true;
    description
      "The binary value of the public key. The interpretation
      of the value is defined by the 'public-key-format' field.";
  }
}

grouping private-key-grouping {
  description
    "A private key.";
  leaf private-key-format {
    nacm:default-deny-write;
    type identityref {
      base private-key-format;
    }
    description
      "Identifies the private key's format. Implementations SHOULD
      ensure that the incoming private key value is encoded in the
      specified format.

      For encrypted keys, the value is the decrypted key's
      format (i.e., the 'encrypted-value-format' conveys the
      encrypted key's format).";
  }
  choice private-key-type {
    nacm:default-deny-write;
    mandatory true;
    description
      "Choice between key types.";
    case cleartext-private-key {
      if-feature "cleartext-private-keys";
      leaf cleartext-private-key {
        nacm:default-deny-all;
        type binary;
        must '../private-key-format';
      }
    }
  }
}

```

```
        description
            "The value of the binary key. The key's value is
            interpreted by the 'private-key-format' field.";
    }
}
case hidden-private-key {
    if-feature "hidden-private-keys";
    leaf hidden-private-key {
        type empty;
        must 'not(..../private-key-format)';
        description
            "A hidden key. It is of type 'empty' as its value is
            inaccessible via management interfaces. Though hidden
            to users, such keys are not hidden to the server and
            may be referenced by configuration to indicate which
            key a server should use for a cryptographic operation.
            How such keys are created is outside the scope of this
            module.";
    }
}
case encrypted-private-key {
    if-feature "encrypted-private-keys";
    container encrypted-private-key {
        must '..../private-key-format';
        description
            "A container for the encrypted asymmetric private key
            value. The interpretation of the 'encrypted-value'
            node is via the 'private-key-format' node";
        uses encrypted-value-grouping;
    }
}
}
}

grouping asymmetric-key-pair-grouping {
    description
        "A private key and, optionally, its associated public key.
        Implementations MUST ensure that the two keys, when both
        are specified, are a matching pair.";
    uses public-key-grouping {
        refine "public-key-format" {
            mandatory false;
        }
        refine "public-key" {
            mandatory false;
        }
    }
    uses private-key-grouping;
}

grouping certificate-expiration-grouping {
    description
        "A notification for when a certificate is about to expire or
        has already expired.";
    notification certificate-expiration {
        if-feature "certificate-expiration-notification";
        description
            "A notification indicating that the configured certificate
```

is either about to expire or has already expired. When to send notifications is an implementation-specific decision, but it is RECOMMENDED that a notification be sent once a month for 3 months, then once a week for four weeks, and then once a day thereafter until the issue is resolved.

If the certificate's issuer maintains a Certificate Revocation List (CRL), the expiration notification MAY be sent if the CRL is about to expire.";

```

leaf expiration-date {
  type yang:date-and-time;
  mandatory true;
  description
    "Identifies the expiration date on the certificate.";
}
}
}

grouping trust-anchor-cert-grouping {
  description
    "A trust anchor certificate and a notification for when
    it is about to expire or has already expired.";
  leaf cert-data {
    nacm:default-deny-all;
    type trust-anchor-cert-cms;
    description
      "The binary certificate data for this certificate.";
  }
  uses certificate-expiration-grouping;
}

grouping end-entity-cert-grouping {
  description
    "An end-entity certificate and a notification for when
    it is about to expire or has already expired. Implementations
    SHOULD assert that, where used, the end-entity certificate
    contains the expected public key.";
  leaf cert-data {
    nacm:default-deny-all;
    type end-entity-cert-cms;
    description
      "The binary certificate data for this certificate.";
  }
  uses certificate-expiration-grouping;
}

grouping generate-csr-grouping {
  description
    "Defines the 'generate-csr' action.";
  action generate-csr {
    if-feature "csr-generation";
    nacm:default-deny-all;
    description
      "Generates a certificate signing request structure for
      the associated asymmetric key using the passed subject
      and attribute values."
  }
}

```

```

    This 'action' statement is only available when the
    associated 'public-key-format' node's value is
    'subject-public-key-info-format'.
input {
  leaf csr-format {
    type identityref {
      base csr-format;
    }
    mandatory true;
    description
      "Specifies the format for the returned certificate.";
  }
  leaf csr-info {
    type csr-info;
    mandatory true;
    description
      "A CertificationRequestInfo structure, as defined in
      RFC 2986.

      Enables the client to provide a fully populated
      CertificationRequestInfo structure that the server
      only needs to sign in order to generate the complete
      CertificationRequest structure to return in the
      'output'.

      The 'AlgorithmIdentifier' field contained inside
      the 'SubjectPublicKeyInfo' field MUST be one known
      to be supported by the device.";
    reference
      "RFC 2986:
       PKCS #10: Certification Request Syntax Specification
      RFC 9640:
       YANG Data Types and Groupings for Cryptography";
  }
}
output {
  choice csr-type {
    mandatory true;
    description
      "A choice amongst certificate signing request formats.
      Additional formats MAY be augmented into this 'choice'
      statement by future efforts.";
    case p10-csr {
      leaf p10-csr {
        type p10-csr;
        description
          "A CertificationRequest, as defined in RFC 2986.";
      }
      description
        "A CertificationRequest, as defined in RFC 2986.";
      reference
        "RFC 2986:
         PKCS #10: Certification Request Syntax Specification
        RFC 9640:
         YANG Data Types and Groupings for Cryptography";
    }
  }
}

```

```
    }
  }
} // generate-csr-grouping

grouping asymmetric-key-pair-with-cert-grouping {
  description
    "A private/public key pair and an associated certificate.
    Implementations MUST assert that the certificate contains
    the matching public key.";
  uses asymmetric-key-pair-grouping;
  uses end-entity-cert-grouping;
  uses generate-csr-grouping;
} // asymmetric-key-pair-with-cert-grouping

grouping asymmetric-key-pair-with-certs-grouping {
  description
    "A private/public key pair and a list of associated
    certificates. Implementations MUST assert that
    certificates contain the matching public key.";
  uses asymmetric-key-pair-grouping;
  container certificates {
    nacm:default-deny-write;
    description
      "Certificates associated with this asymmetric key.";
    list certificate {
      key "name";
      description
        "A certificate for this asymmetric key.";
      leaf name {
        type string;
        description
          "An arbitrary name for the certificate.";
      }
      uses end-entity-cert-grouping {
        refine "cert-data" {
          mandatory true;
        }
      }
    }
  }
  uses generate-csr-grouping;
} // asymmetric-key-pair-with-certs-grouping
}

<CODE ENDS>
```

3. Security Considerations

3.1. No Support for CRMF

This document uses PKCS #10 [RFC2986] for the "generate-csr" action. The use of Certificate Request Message Format (CRMF) [RFC4211] was considered, but it was unclear if there was market demand for it. If it is desired to support CRMF in the future, a backwards compatible solution can be defined at that time.

3.2. No Support for Key Generation

Early revisions of this document included "rpc" statements for generating symmetric and asymmetric keys. These statements were removed due to an inability to obtain consensus for how to generically identify the key algorithm to use. Hence, the solution presented in this document only supports keys to be configured via an external client.

Separate protocol-specific modules can present protocol-specific key-generating RPCs (e.g., the "generate-asymmetric-key-pair" RPC in [\[RFC9644\]](#) and [\[RFC9645\]](#)).

3.3. Unconstrained Public Key Usage

This module defines the "public-key-grouping" grouping, which enables the configuration of public keys without constraints on their usage, e.g., what operations the key is allowed to be used for (e.g., encryption, verification, or both).

The "asymmetric-key-pair-grouping" grouping uses the aforementioned "public-key-grouping" grouping and carries the same traits.

The "asymmetric-key-pair-with-cert-grouping" grouping uses the aforementioned "asymmetric-key-pair-grouping" grouping, whereby associated certificates **MUST** constrain the usage of the public key according to local policy.

3.4. Unconstrained Private Key Usage

This module defines the "asymmetric-key-pair-grouping" grouping, which enables the configuration of private keys without constraints on their usage, e.g., what operations the key is allowed to be used for (e.g., signature, decryption, or both).

The "asymmetric-key-pair-with-cert-grouping" grouping uses the aforementioned "asymmetric-key-pair-grouping" grouping, whereby configured certificates (e.g., identity certificates) may constrain the use of the public key according to local policy.

3.5. Cleartext Passwords and Keys

The module contained within this document enables, only when specific "feature" statements are enabled, for the cleartext value of passwords and keys to be stored in the configuration database. Storing cleartext values for passwords and keys is **NOT RECOMMENDED**.

3.6. Encrypting Passwords and Keys

The module contained within this document enables cleartext passwords and keys to be encrypted via another key, either symmetric or asymmetric. Both formats use a CMS structure (EncryptedData and EnvelopedData, respectively), which allows any encryption algorithm to be used.

To securely encrypt a password or key with a symmetric key, a proper block cipher mode, such as an Authenticated Encryption with Associated Data (AEAD) or Cipher Block Chaining (CBC), **MUST** be used. This ensures that a random Initialization Vector (IV) is part of the input, which guarantees that the output for encrypting the same password or key still produces a different unpredictable ciphertext. This avoids leaking that some encrypted keys or passwords are the same and makes it much harder to pre-generate rainbow tables to brute-force attack weak passwords. The Electronic Codebook (ECB) block cipher mode **MUST NOT** be used.

3.7. Deletion of Cleartext Key Values

This module defines storage for cleartext key values that **SHOULD** be zeroized when deleted so as to prevent the remnants of their persisted storage locations from being analyzed in any meaningful way.

The cleartext key values are the "cleartext-symmetric-key" node defined in the "symmetric-key-grouping" grouping ([Section 2.1.4.3](#)) and the "cleartext-private-key" node defined in the "asymmetric-key-pair-grouping" grouping ([Section 2.1.4.6](#)).

3.8. Considerations for the "ietf-crypto-types" YANG Module

This section is modeled after the template defined in [Section 3.7.1](#) of [\[RFC8407\]](#).

The "ietf-crypto-types" YANG module defines "grouping" statements that are designed to be accessed via YANG-based management protocols, such as NETCONF [\[RFC6241\]](#) and RESTCONF [\[RFC8040\]](#). Both of these protocols have mandatory-to-implement secure transport layers (e.g., Secure Shell (SSH) [\[RFC4252\]](#), TLS [\[RFC8446\]](#), and QUIC [\[RFC9000\]](#)) and mandatory-to-implement mutual authentication.

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

Since the module in this document only defines groupings, these considerations are primarily for the designers of other modules that use these groupings.

Some of the readable data nodes defined 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. The following subtrees and data nodes have particular sensitivity/vulnerability:

- The "cleartext-password" node:

The "cleartext-password" node defined in the "password-grouping" grouping is additionally sensitive to read operations such that, in normal use cases, it should never be returned to a client. For this reason, the NACM extension "default-deny-all" has been applied to it.

- The "cleartext-symmetric-key" node:

The "cleartext-symmetric-key" node defined in the "symmetric-key-grouping" grouping is additionally sensitive to read operations such that, in normal use cases, it should never be returned to a client. For this reason, the NACM extension "default-deny-all" has been applied to it.

- The "cleartext-private-key" node:

The "cleartext-private-key" node defined in the "asymmetric-key-pair-grouping" grouping is additionally sensitive to read operations such that, in normal use cases, it should never be returned to a client. For this reason, the NACM extension "default-deny-all" has been applied to it.

- The "cert-data" node:

The "cert-data" node defined in both the "trust-anchor-cert-grouping" and "end-entity-cert-grouping" groupings is additionally sensitive to read operations, as certificates may provide insight into which other resources/applications/servers this particular server communicates with, as well as potentially divulge personally identifying information (e.g., end-entity certificates). For this reason, the NACM extension "default-deny-all" has been applied to it.

All the writable data nodes defined by all the groupings defined in this module may be considered sensitive or vulnerable in some network environments. For instance, even the modification of a public key or a certificate can dramatically alter the implemented security policy. For this reason, the NACM extension "default-deny-write" has been applied to all the data nodes defined in the module.

Some of the operations in this YANG module may be considered sensitive or vulnerable in some network environments. It is thus important to control access to these operations. These are the operations and their sensitivity/vulnerability:

- generate-csr:

This "action" statement **SHOULD** only be executed by authorized users. For this reason, the NACM extension "default-deny-all" has been applied. Note that NACM uses "default-deny-all" to protect "rpc" and "action" statements; it does not define, e.g., an extension called "default-deny-execute".

For this action, it is **RECOMMENDED** that implementations assert channel binding [RFC5056] so as to ensure that the application layer that sent the request is the same as the device authenticated when the secure transport layer was established.

4. IANA Considerations

4.1. The IETF XML Registry

IANA has registered the following URI in the "ns" registry of the "IETF XML Registry" [RFC3688].

URI: urn:ietf:params:xml:ns:yang:ietf-crypto-types
Registrant Contact: The IESG
XML: N/A; the requested URI is an XML namespace.

4.2. The YANG Module Names Registry

IANA has registered the following YANG module in the "YANG Module Names" registry [RFC6020].

Name: ietf-crypto-types
Namespace: urn:ietf:params:xml:ns:yang:ietf-crypto-types
Prefix: ct
Reference: RFC 9640

5. References

5.1. Normative References

- [ITU.X680.2021] ITU-T, "Information technology - Abstract Syntax Notation One (ASN.1): Specification of basic notation", ITU-T Recommendation X.680, ISO/IEC 8824-1:2021, February 2021, <<https://www.itu.int/rec/T-REC-X.680-202102-I>>.
- [ITU.X690.2021] ITU-T, "Information Technology - ASN.1 encoding rules: Specification of Basic Encoding Rules (BER), Canonical Encoding Rules (CER) and Distinguished Encoding Rules (DER)", ITU-T Recommendation X.690, ISO/IEC 8825-1:2021, February 2021, <<https://www.itu.int/rec/T-REC-X.690-202102-I>>.
- [RFC2119] Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", BCP 14, RFC 2119, DOI 10.17487/RFC2119, March 1997, <<https://www.rfc-editor.org/info/rfc2119>>.
- [RFC2986] Nystrom, M. and B. Kaliski, "PKCS #10: Certification Request Syntax Specification Version 1.7", RFC 2986, DOI 10.17487/RFC2986, November 2000, <<https://www.rfc-editor.org/info/rfc2986>>.
- [RFC4252] Ylonen, T. and C. Lonvick, Ed., "The Secure Shell (SSH) Authentication Protocol", RFC 4252, DOI 10.17487/RFC4252, January 2006, <<https://www.rfc-editor.org/info/rfc4252>>.
- [RFC4253] Ylonen, T. and C. Lonvick, Ed., "The Secure Shell (SSH) Transport Layer Protocol", RFC 4253, DOI 10.17487/RFC4253, January 2006, <<https://www.rfc-editor.org/info/rfc4253>>.
- [RFC5280] Cooper, D., Santesson, S., Farrell, S., Boeyen, S., Housley, R., and W. Polk, "Internet X.509 Public Key Infrastructure Certificate and Certificate Revocation List (CRL) Profile", RFC 5280, DOI 10.17487/RFC5280, May 2008, <<https://www.rfc-editor.org/info/rfc5280>>.

-
- [RFC5652] Housley, R., "Cryptographic Message Syntax (CMS)", STD 70, RFC 5652, DOI 10.17487/RFC5652, September 2009, <<https://www.rfc-editor.org/info/rfc5652>>.
- [RFC5915] Turner, S. and D. Brown, "Elliptic Curve Private Key Structure", RFC 5915, DOI 10.17487/RFC5915, June 2010, <<https://www.rfc-editor.org/info/rfc5915>>.
- [RFC5958] Turner, S., "Asymmetric Key Packages", RFC 5958, DOI 10.17487/RFC5958, August 2010, <<https://www.rfc-editor.org/info/rfc5958>>.
- [RFC6031] Turner, S. and R. Housley, "Cryptographic Message Syntax (CMS) Symmetric Key Package Content Type", RFC 6031, DOI 10.17487/RFC6031, December 2010, <<https://www.rfc-editor.org/info/rfc6031>>.
- [RFC6241] Enns, R., Ed., Bjorklund, M., Ed., Schoenwaelder, J., Ed., and A. Bierman, Ed., "Network Configuration Protocol (NETCONF)", RFC 6241, DOI 10.17487/RFC6241, June 2011, <<https://www.rfc-editor.org/info/rfc6241>>.
- [RFC6960] Santesson, S., Myers, M., Ankney, R., Malpani, A., Galperin, S., and C. Adams, "X.509 Internet Public Key Infrastructure Online Certificate Status Protocol - OCSP", RFC 6960, DOI 10.17487/RFC6960, June 2013, <<https://www.rfc-editor.org/info/rfc6960>>.
- [RFC6991] Schoenwaelder, J., Ed., "Common YANG Data Types", RFC 6991, DOI 10.17487/RFC6991, July 2013, <<https://www.rfc-editor.org/info/rfc6991>>.
- [RFC7093] Turner, S., Kent, S., and J. Manger, "Additional Methods for Generating Key Identifiers Values", RFC 7093, DOI 10.17487/RFC7093, December 2013, <<https://www.rfc-editor.org/info/rfc7093>>.
- [RFC7950] Bjorklund, M., Ed., "The YANG 1.1 Data Modeling Language", RFC 7950, DOI 10.17487/RFC7950, August 2016, <<https://www.rfc-editor.org/info/rfc7950>>.
- [RFC8017] Moriarty, K., Ed., Kaliski, B., Jonsson, J., and A. Rusch, "PKCS #1: RSA Cryptography Specifications Version 2.2", RFC 8017, DOI 10.17487/RFC8017, November 2016, <<https://www.rfc-editor.org/info/rfc8017>>.
- [RFC8040] Bierman, A., Bjorklund, M., and K. Watsen, "RESTCONF Protocol", RFC 8040, DOI 10.17487/RFC8040, January 2017, <<https://www.rfc-editor.org/info/rfc8040>>.
- [RFC8174] Leiba, B., "Ambiguity of Uppercase vs Lowercase in RFC 2119 Key Words", BCP 14, RFC 8174, DOI 10.17487/RFC8174, May 2017, <<https://www.rfc-editor.org/info/rfc8174>>.
- [RFC8341] Bierman, A. and M. Bjorklund, "Network Configuration Access Control Model", STD 91, RFC 8341, DOI 10.17487/RFC8341, March 2018, <<https://www.rfc-editor.org/info/rfc8341>>.
- [RFC8446] Rescorla, E., "The Transport Layer Security (TLS) Protocol Version 1.3", RFC 8446, DOI 10.17487/RFC8446, August 2018, <<https://www.rfc-editor.org/info/rfc8446>>.

- [RFC9000] Iyengar, J., Ed. and M. Thomson, Ed., "QUIC: A UDP-Based Multiplexed and Secure Transport", RFC 9000, DOI 10.17487/RFC9000, May 2021, <<https://www.rfc-editor.org/info/rfc9000>>.

5.2. Informative References

- [HTTP-CLIENT-SERVER] Watsen, K., "YANG Groupings for HTTP Clients and HTTP Servers", Work in Progress, Internet-Draft, draft-ietf-netconf-http-client-server-23, 15 August 2024, <<https://datatracker.ietf.org/doc/html/draft-ietf-netconf-http-client-server-23>>.
- [NETCONF-CLIENT-SERVER] Watsen, K., "NETCONF Client and Server Models", Work in Progress, Internet-Draft, draft-ietf-netconf-netconf-client-server-37, 14 August 2024, <<https://datatracker.ietf.org/doc/html/draft-ietf-netconf-netconf-client-server-37>>.
- [RESTCONF-CLIENT-SERVER] Watsen, K., "RESTCONF Client and Server Models", Work in Progress, Internet-Draft, draft-ietf-netconf-restconf-client-server-38, 14 August 2024, <<https://datatracker.ietf.org/doc/html/draft-ietf-netconf-restconf-client-server-38>>.
- [RFC3688] Mealling, M., "The IETF XML Registry", BCP 81, RFC 3688, DOI 10.17487/RFC3688, January 2004, <<https://www.rfc-editor.org/info/rfc3688>>.
- [RFC4211] Schaad, J., "Internet X.509 Public Key Infrastructure Certificate Request Message Format (CRMF)", RFC 4211, DOI 10.17487/RFC4211, September 2005, <<https://www.rfc-editor.org/info/rfc4211>>.
- [RFC5056] Williams, N., "On the Use of Channel Bindings to Secure Channels", RFC 5056, DOI 10.17487/RFC5056, November 2007, <<https://www.rfc-editor.org/info/rfc5056>>.
- [RFC6020] Bjorklund, M., Ed., "YANG - A Data Modeling Language for the Network Configuration Protocol (NETCONF)", RFC 6020, DOI 10.17487/RFC6020, October 2010, <<https://www.rfc-editor.org/info/rfc6020>>.
- [RFC7317] Bierman, A. and M. Bjorklund, "A YANG Data Model for System Management", RFC 7317, DOI 10.17487/RFC7317, August 2014, <<https://www.rfc-editor.org/info/rfc7317>>.
- [RFC8259] Bray, T., Ed., "The JavaScript Object Notation (JSON) Data Interchange Format", STD 90, RFC 8259, DOI 10.17487/RFC8259, December 2017, <<https://www.rfc-editor.org/info/rfc8259>>.
- [RFC8340] Bjorklund, M. and L. Berger, Ed., "YANG Tree Diagrams", BCP 215, RFC 8340, DOI 10.17487/RFC8340, March 2018, <<https://www.rfc-editor.org/info/rfc8340>>.
- [RFC8342] Bjorklund, M., Schoenwaelder, J., Shafer, P., Watsen, K., and R. Wilton, "Network Management Datastore Architecture (NMDA)", RFC 8342, DOI 10.17487/RFC8342, March 2018, <<https://www.rfc-editor.org/info/rfc8342>>.

- [RFC8407] Bierman, A., "Guidelines for Authors and Reviewers of Documents Containing YANG Data Models", BCP 216, RFC 8407, DOI 10.17487/RFC8407, October 2018, <<https://www.rfc-editor.org/info/rfc8407>>.
- [RFC8792] Watsen, K., Auerswald, E., Farrel, A., and Q. Wu, "Handling Long Lines in Content of Internet-Drafts and RFCs", RFC 8792, DOI 10.17487/RFC8792, June 2020, <<https://www.rfc-editor.org/info/rfc8792>>.
- [RFC9641] Watsen, K., "A YANG Data Model for a Truststore", RFC 9641, DOI 10.17487/RFC9641, October 2024, <<https://www.rfc-editor.org/info/rfc9641>>.
- [RFC9642] Watsen, K., "A YANG Data Model for a Keystore", RFC 9642, DOI 10.17487/RFC9642, October 2024, <<https://www.rfc-editor.org/info/rfc9642>>.
- [RFC9643] Watsen, K. and M. Scharf, "YANG Groupings for TCP Clients and TCP Servers", RFC 9643, DOI 10.17487/RFC9643, October 2024, <<https://www.rfc-editor.org/info/rfc9643>>.
- [RFC9644] Watsen, K., "YANG Groupings for SSH Clients and SSH Servers", RFC 9644, DOI 10.17487/RFC9644, October 2024, <<https://www.rfc-editor.org/info/rfc9644>>.
- [RFC9645] Watsen, K., "YANG Groupings for TLS Clients and TLS Servers", RFC 9645, DOI 10.17487/RFC9645, October 2024, <<https://www.rfc-editor.org/info/rfc9645>>.
- [W3C.REC-xml-20081126] Bray, T., Paoli, J., Sperberg-McQueen, C.M., Maler, E., and F. Yergeau, "Extensible Markup Language (XML) 1.0 (Fifth Edition)", World Wide Web Consortium Recommendation REC-xml-20081126, November 2008, <<https://www.w3.org/TR/2008/REC-xml-20081126/>>.

Acknowledgements

The authors would like to thank the following for lively discussions on list and in the halls (ordered by first name): Balázs Kovács, Carsten Bormann, Dale Worley, Eric Voit, Éric Vyncke, Francesca Palombini, Jürgen Schönwälder, Lars Eggert, Liang Xia, Mahesh Jethanandani, Martin Björklund, Murray Kucherawy, Nick Hancock, Ori Steele, Paul Wouters, Rich Salz, Rifaat Shekh-Yusef, Rob Wilton, Roman Danyliw, Russ Housley, Sandra Murphy, Tom Petch, Valery Smyslov, Wang Haiguang, Warren Kumari, and Zaheduzzaman Sarker.

Author's Address

Kent Watsen

Watsen Networks

Email: kent+ietf@watsen.net