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Authors:	H. Brockhaus <i>Siemens</i>	D. von Oheimb <i>Siemens</i>	M. Ounsworth <i>Entrust</i>	J. Gray <i>Entrust</i>

RFC 9810

Internet X.509 Public Key Infrastructure -- Certificate Management Protocol (CMP)

Abstract

This document describes the Internet X.509 Public Key Infrastructure (PKI) Certificate Management Protocol (CMP). Protocol messages are defined for X.509v3 certificate creation and management. CMP provides interactions between client systems and PKI components such as a Registration Authority (RA) and a Certification Authority (CA).

This document adds support for management of certificates containing a Key Encapsulation Mechanism (KEM) public key and uses EnvelopedData instead of EncryptedValue. This document also includes the updates specified in Section 2 and Appendix A.2 of RFC 9480.

This document obsoletes RFC 4210, and together with RFC 9811, it also obsoletes RFC 9480. Appendix F of this document updates Section 9 of RFC 5912.

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1. Introduction

This document describes the Internet X.509 PKI CMP. Protocol messages are defined for certificate creation and management. The term "certificate" in this document refers to an X.509v3 certificate as defined in [RFC5280].

1.1. Changes Made by RFC 4210

[RFC4210] differs from [RFC2510] in the following areas:

- The PKI management message profile section is split to two appendices: the required profile and the optional profile. Some of the formerly mandatory functionality is moved to the optional profile.
- The message confirmation mechanism has changed substantially.
- A new polling mechanism is introduced, deprecating the old polling method at the CMP transport level.
- The CMP transport protocol issues are handled in a separate document [RFC6712], thus the "Transports" section is removed.
- A new implicit confirmation method is introduced to reduce the number of protocol messages exchanged in a transaction.
- The new specification contains some less prominent protocol enhancements and improved explanatory text on several issues.

1.2. Updates Made by RFC 9480

CMP Updates [RFC9480] and CMP Algorithms [RFC9481] updated [RFC4210], supporting the PKI management operations specified in the Lightweight CMP Profile [RFC9483], in the following areas:

- Added new extended key usages (EKUs) for various CMP server types, e.g., RA and CA, to express the authorization of the certificate holder that acts as the indicated type of PKI management entity.
- Extended the description of multiple protection to cover additional use cases, e.g., batch processing of messages.
- Used the Cryptographic Message Syntax (CMS) [RFC5652] type EnvelopedData as the preferred choice instead of EncryptedValue to better support crypto agility in CMP.

For reasons of completeness and consistency, the type EncryptedValue has been exchanged in all occurrences. This includes the protection of centrally generated private keys, encryption of certificates, Proof-of-Possession (POP) methods, and protection of revocation passphrases. To properly differentiate the support of EnvelopedData instead of EncryptedValue, CMP version 3 is introduced in case a transaction is supposed to use EnvelopedData.

Note: According to point 9 in [Section 2.1](#) of [RFC4211], the use of the EncryptedValue structure has been deprecated in favor of the EnvelopedData structure. [RFC4211] offers the EncryptedKey structure a choice of EncryptedValue and EnvelopedData for migration to EnvelopedData.

- Offered an optional hashAlg field in CertStatus supporting cases when a certificate needs to be confirmed, but the certificate was signed using a signature algorithm that does not indicate a specific hash algorithm to use for computing the certHash. This is also in preparation for upcoming post-quantum algorithms.
- Added new general message types to request CA certificates, a root CA update, a certificate request template, or Certificate Revocation List (CRL) updates.
- Extended the use of polling to p10cr, certConf, rr, genm, and error messages.
- Deleted the mandatory algorithm profile in [Appendix C.2](#) and instead referred to [Section 7](#) of [\[RFC9481\]](#).
- Added [Sections 8.6, 8.7, 8.9, and 8.10](#) to the security considerations.

1.3. Changes Made by This Document

This document obsoletes [\[RFC4210\]](#) and [\[RFC9480\]](#).

Backward compatibility with CMP version 2 is maintained wherever possible. Updates to CMP version 2 improve crypto agility, extend the polling mechanism, add new general message types, and add EKUs to identify special CMP server authorizations. CMP version 3 is introduced for changes to the ASN.1 syntax, which support EnvelopedData, certConf with hashAlg, POPOPrivKey with agreeMAC, and RootCaKeyUpdateContent in ckuann messages.

The updates made in this document include the changes specified by [Section 2](#) and [Appendix A.2](#) of [\[RFC9480\]](#) as described in [Section 1.2](#). Additionally, this document updates the content of [\[RFC4210\]](#) in the following areas:

- Added [Section 3.1.1.4](#) introducing the Key Generation Authority (KGA).
- Extended [Section 3.1.2](#) regarding use of Certificate Transparency (CT) logs.
- Updated [Section 4.4](#) introducing RootCaKeyUpdateContent as an alternative to using a repository to acquire new root CA certificates.
- Added [Section 5.1.1.3](#) containing a description of origPKIMessage content, moved here from [Section 5.1.3.4](#).
- Added support for KEM keys for POP to [Sections 4.3](#) and [5.2.8](#), for message protection to [Sections 5.1.1](#) and [5.1.3.4](#) and [Appendix E](#), and for usage with CMS EnvelopedData to [Section 5.2.2](#).
- Deprecated CAKeyUpdAnnContent in favor of RootCaKeyUpdateContent.
- Incorporated the request message behavioral clarifications from [Appendix C](#) of [\[RFC4210\]](#) to [Section 5](#). The definition of altCertTemplate was incorporated into [Section 5.2.1](#), and the clarification on POPOSigningKey and on POPOPrivKey was incorporated into [Section 5.2.8](#).
- Added support for CMS EnvelopedData to different POP methods for transferring encrypted private keys, certificates, and challenges to [Section 5.2.8](#).
- Added [Sections 8.1, 8.5, 8.8, and 8.11](#) to the security considerations.

2. Terminology and Abbreviations

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.

This document relies on the terminology defined in [[RFC5280](#)]. The most important abbreviations are listed below:

CA: Certification Authority

CMP: Certificate Management Protocol

CMS: Cryptographic Message Syntax

CRL: Certificate Revocation List

CRMF: Certificate Request Message Format

EE: End Entity

KEM: Key Encapsulation Mechanism

KGA: Key Generation Authority

LRA: Local Registration Authority

MAC: Message Authentication Code

PKI: Public Key Infrastructure

POP: Proof-of-Possession

RA: Registration Authority

TEE: Trusted Execution Environment

3. PKI Management Overview

The PKI must be structured to be consistent with the types of individuals who must administer it. Providing such administrators with unbounded choices not only complicates the software required but also increases the chances that a subtle mistake by an administrator or software developer will result in broader compromise. Similarly, restricting administrators with cumbersome mechanisms will cause them not to use the PKI.

Management protocols are **REQUIRED** to support online interactions between PKI components. For example, a management protocol might be used between a CA and a client system with which a key pair is associated or between two CAs that issue cross-certificates for each other.

3.1. PKI Management Model

Before specifying particular message formats and procedures, we first define the entities involved in PKI management and their interactions (in terms of the PKI management functions required). We then group these functions in order to accommodate different identifiable types of EEs.

3.1.1. Definitions of PKI Entities

The entities involved in PKI management include the EE (i.e., the entity to whom the certificate is issued) and the CA (i.e., the entity that issues the certificate). An RA might also be involved in PKI management.

3.1.1.1. Subjects and End Entities

The term "subject" is used here to refer to the entity to whom the certificate is issued, typically named in the subject or subjectAltName field of a certificate. When we wish to distinguish the tools and/or software used by the subject (e.g., a local certificate management module), we will use the term "subject equipment". In general, the term "end entity" (EE), rather than "subject", is preferred in order to avoid confusion with the field name. It is important to note that the EEs here will include not only human users of applications but also applications themselves (e.g., for Internet Key Exchange Protocol (IKE) / IPsec) or devices (e.g., routers or industrial control systems). This factor influences the protocols that the PKI management operations use; for example, application software is far more likely to know exactly which certificate extensions are required than are human users. PKI management entities are also EEs in the sense that they are sometimes named in the subject or subjectAltName field of a certificate or cross-certificate. Where appropriate, the term "end entity" will be used to refer to EEs who are not PKI management entities.

All EEs require secure local access to some information -- at a minimum, their own name and private key, the name of a CA that is directly trusted by this entity, and that CA's public key (or a fingerprint of the public key where a self-certified version is available elsewhere).

Implementations **MAY** use secure local storage for more than this minimum (e.g., the EE's own certificates or application-specific information). The form of storage will also vary -- from files to tamper-resistant cryptographic tokens. The information stored in such local, trusted storage is referred to here as the EE's TEE, also known as Personal Security Environment (PSE).

Though TEE formats are beyond the scope of this document (they are very dependent on equipment, et cetera), a generic interchange format for TEEs is defined here: a certification response message (see [Section 5.3.4](#)) **MAY** be used.

3.1.1.2. Certification Authority

The CA may or may not actually be a real "third party" from the EE's point of view. Quite often, the CA will actually belong to the same organization as the EEs it supports.

Again, we use the term "CA" to refer to the entity named in the issuer field of a certificate. When it is necessary to distinguish the software or hardware tools used by the CA, we use the term "CA equipment".

The CA equipment will often include both an "offline" component and an "online" component, with the CA private key only available to the "offline" component. This is, however, a matter for implementers (though it is also relevant as a policy issue).

We use the term "root CA" to indicate a CA that is directly trusted by an EE; that is, securely acquiring the value of a root CA public key requires some out-of-band step(s). This term is not meant to imply that a root CA is necessarily at the top of any hierarchy, simply that the CA in question is trusted directly. The "root CA" may provide its trust anchor information with or without using a certificate. In some circumstances, such a certificate may be self-signed, but in other circumstances, it may be cross-signed, signed by a peer, signed by a superior CA, or unsigned.

Note that other documents like [\[X509.2019\]](#) and [\[RFC5280\]](#) use the term "trusted CA" or "trust anchor" instead of "root CA". This document continues using "root CA" based on the above definition because it is also present in the ASN.1 syntax that cannot be changed easily.

A "subordinate CA" is one that is not a root CA for the EE in question. Often, a subordinate CA will not be a root CA for any entity, but this is not mandatory.

3.1.1.3. Registration Authority

In addition to EEs and CAs, many environments call for the existence of an RA separate from the CA. The functions that the RA may carry out will vary from case to case but **MAY** include identity checking, token distribution, checking certificate requests and authentication of their origin, revocation reporting, name assignment, archival of key pairs, et cetera.

This document views the RA as an **OPTIONAL** component: When it is not present, the CA is assumed to be able to carry out the RA's functions so that the PKI management protocols are the same from the EE's point of view.

Again, we distinguish, where necessary, between the RA and the tools used (the "RA equipment").

Note that an RA is itself an EE. We further assume that all RAs are in fact certified EEs and that RAs have private keys that are usable for signing. How a particular CA equipment identifies some EEs as RAs is an implementation issue (i.e., this document specifies no special RA certification operation). We do not mandate that the RA is certified by the CA with which it is interacting at the moment (so one RA may work with more than one CA whilst only being certified once).

In some circumstances, EEs will communicate directly with a CA even where an RA is present. For example, for initial registration and/or certification, the EE may use its RA but communicate directly with the CA in order to refresh its certificate.

3.1.1.4. Key Generation Authority

A KGA is a PKI management entity generating key pairs on behalf of an EE. As the KGA generates the key pair, it knows the public and the private part.

This document views the KGA as an **OPTIONAL** component. When it is not present and central key generation is needed, the CA is assumed to be able to carry out the KGA's functions so that the PKI management protocol messages are the same from the EE's point of view. If certain tasks of a CA are delegated to other components, this delegation needs authorization, which can be indicated by EKUs (see [Section 4.5](#)).

Note: When doing central generation of key pairs, implementers should consider the implications of server-side retention on the overall security of the system; in some cases, retention is good, for example, for escrow reasons, but in other cases, the server should clear its copy after delivery to the EE.

Note: If the CA delegates key generation to a KGA, the KGA can be collocated with the RA.

3.1.2. PKI Management Requirements

The protocols given here meet the following requirements on PKI management

1. PKI management must conform to the ISO/IEC 9594-8/ITU-T X.509 standards, in particular [\[X509.2019\]](#).
2. It must be possible to regularly update any key pair without affecting any other key pair.
3. The use of confidentiality in PKI management protocols must be kept to a minimum in order to ease acceptance in environments where strong confidentiality might cause regulatory problems.
4. PKI management protocols must allow the use of different industry-standard cryptographic algorithms (see CMP Algorithms [\[RFC9481\]](#)). This means that any given CA, RA, or EE may, in principle, use whichever algorithms suit it for its own key pair(s).
5. PKI management protocols must not preclude the generation of key pairs by the EE concerned, by a KGA, or by a CA. Key generation may also occur elsewhere, but for the purposes of PKI management, we can regard key generation as occurring wherever the key is first present at an EE, KGA, or CA.
6. PKI management protocols must support the publication of certificates by the EE concerned, by an RA, or by a CA. Different implementations and different environments may choose any of the above approaches.
7. PKI management protocols must support the production of Certificate Revocation Lists (CRLs) by allowing certified EEs to make requests for the revocation of certificates. This must be done in such a way that the denial-of-service attacks, which are possible, are not made simpler.
8. PKI management protocols must be usable over a variety of "transport" mechanisms, specifically including email, Hypertext Transfer Protocol (HTTP), Message Queuing Telemetry Transport (MQTT), Constrained Application Protocol (CoAP), and various offline and non-networked file transfer methods.

9. Final authority for certification creation rests with the CA. No RA or EE equipment can assume that any certificate issued by a CA will contain what was requested; a CA may alter certificate field values or may add, delete, or alter extensions according to its operating policy. In other words, all PKI entities (EEs, RAs, KGAs, and CAs) must be capable of handling responses to requests for certificates in which the actual certificate issued is different from that requested (for example, a CA may shorten the validity period requested). Note that policy may dictate that the CA must not publish or otherwise distribute the certificate until the requesting entity has reviewed and accepted the newly created certificate or the POP is completed. In case of publication of the certificate (when using indirect POP, see [Section 8.11](#)) or a precertificate in a CT log [[RFC9162](#)], the certificate must be revoked if it was not accepted by the EE or the POP could not be completed.
10. A graceful, scheduled changeover from one non-compromised CA key pair to the next (CA key update) must be supported (note that if the CA key is compromised, re-initialization must be performed for all entities in the domain of that CA). An EE whose TEE contains the new CA public key (following a CA key update) may also need to be able to verify certificates verifiable using the old public key. EEs who directly trust the old CA key pair may also need to be able to verify certificates signed using the new CA private key (required for situations where the old CA public key is "hardwired" into the EE's cryptographic equipment).
11. The functions of an RA may, in some implementations or environments, be carried out by the CA itself. The protocols must be designed so that EEs will use the same protocol regardless of whether the communication is with an RA or CA. Naturally, the EE must use the correct RA or CA public key to verify the protection of the communication.
12. Where an EE requests a certificate containing a given public key value, the EE must be ready to demonstrate possession of the corresponding private key value. This may be accomplished in various ways, depending on the type of certification request. See [Section 4.3](#) for details of the in-band methods defined for the PKIX-CMP (i.e., CMP) messages.

3.1.3. PKI Management Operations

The following diagram shows the relationship between the entities defined above in terms of the PKI management operations. The letters in the diagram indicate "protocols" in the sense that a defined set of PKI management messages can be sent along each of the lettered lines.

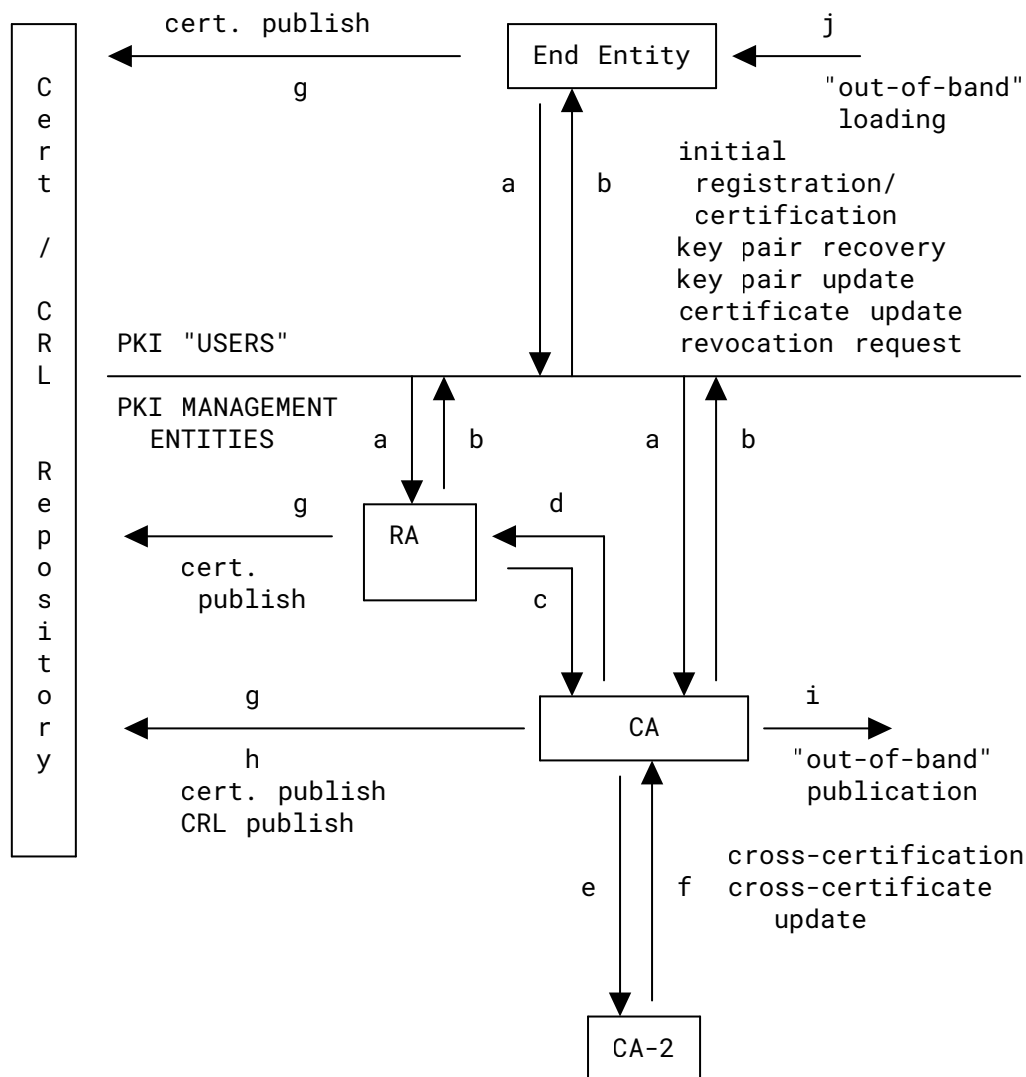


Figure 1: PKI Entities

At a high level, the set of operations for which management messages are defined can be grouped as follows.

1. CA establishment: When establishing a new CA, certain steps are required (e.g., production of initial CRLs and export of CA public key).
2. End entity initialization: This includes importing a root CA public key and requesting information about the options supported by a PKI management entity.
3. Certification: Various operations result in the creation of new certificates:
 - a. initial registration/certification: This is the process whereby an EE first makes itself known to a CA or RA, prior to the CA issuing a certificate or certificates for that EE. The end result

of this process (when it is successful) is that a CA issues a certificate for an EE's public key and returns that certificate to the EE and/or posts that certificate in a repository. This process may, and typically will, involve multiple "steps", possibly including an initialization of the EE's equipment. For example, the EE's equipment must be securely initialized with the public key of a CA, e.g., using zero-touch methods like Bootstrapping Remote Secure Key Infrastructure (BRSKI) [RFC8995] or Secure Zero Touch Provisioning (SZTP) [RFC8572], to be used in validating certificate paths. Furthermore, an EE typically needs to be initialized with its own key pair(s).

- b. key pair update: Every key pair needs to be updated regularly (i.e., replaced with a new key pair), and a new certificate needs to be issued.
- c. certificate update: As certificates expire, they may be "refreshed" if nothing relevant in the environment has changed.
- d. CA key pair update: As with EEs, CA key pairs need to be updated regularly; however, different mechanisms are required.
- e. cross-certification request: One CA requests issuance of a cross-certificate from another CA. For the purposes of this standard, the following terms are defined. A "cross-certificate" is a certificate in which the subject CA and the issuer CA are distinct and SubjectPublicKeyInfo contains a verification key (i.e., the certificate has been issued for the subject CA's signing key pair). When it is necessary to distinguish more finely, the following terms may be used: A cross-certificate is called an "inter-domain cross-certificate" if the subject and issuer CAs belong to different administrative domains; it is called an "intra-domain cross-certificate" otherwise.

Note 1: The above definition of "cross-certificate" aligns with the defined term "CA-certificate" in X.509. Note that this term is not to be confused with the X.500 "cACertificate" attribute type, which is unrelated.

Note 2: In many environments, the term "cross-certificate", unless further qualified, will be understood to be synonymous with "inter-domain cross-certificate" as defined above.

Note 3: Issuance of cross-certificates may be, but is not necessarily, mutual; that is, two CAs may issue cross-certificates for each other.

- f. cross-certificate update: Similar to a normal certificate update but involving a cross-certificate.
4. Certificate/CRL discovery operations: Some PKI management operations result in the publication of certificates or CRLs:
- a. certificate publication: Having gone to the trouble of producing a certificate, some means for publishing may be needed. The "means" defined in PKIX **MAY** involve the messages specified in Sections 5.3.13 to 5.3.16 or **MAY** involve other methods (for example, Lightweight Directory Access Protocol (LDAP)) as described in [RFC4511] or [RFC2585] (the "Operational Protocols" documents of the PKIX series of specifications).
 - b. CRL publication: As for certificate publication.

5. Recovery operations: Some PKI management operations are used when an EE has "lost" its TEE:
 - a. key pair recovery: As an option, user client key materials (e.g., a user's private key used for decryption purposes) **MAY** be backed up by a CA, an RA, or a key backup system associated with a CA or RA. If an entity needs to recover these backed up key materials (e.g., as a result of a forgotten password or a lost key chain file), a protocol exchange may be needed to support such recovery.
6. Revocation operations: Some PKI management operations result in the creation of new CRL entries and/or new CRLs:
 - a. revocation request: An authorized person advises a CA of an abnormal situation requiring certificate revocation.
7. TEE operations: Whilst the definition of TEE operations (e.g., moving a TEE, changing a PIN, etc.) are beyond the scope of this specification, we do define a PKIMessage (CertRepMessage) that can form the basis of such operations.

Note that online protocols are not the only way of implementing the above operations. For all operations, there are offline methods of achieving the same result, and this specification does not mandate use of online protocols. For example, when hardware tokens are used, many of the operations **MAY** be achieved as part of the physical token delivery.

Later sections define a set of standard messages supporting the above operations. Transfer protocols for conveying these exchanges in various environments (e.g., offline: file-based; online: mail, HTTP [[RFC9811](#)], MQTT, and CoAP [[RFC9482](#)]) are beyond the scope of this document and must be specified separately. Appropriate transfer protocols **MUST** be capable of delivering the CMP messages reliably.

CMP provides inbuilt integrity protection and authentication. The information communicated unencrypted in CMP messages does not contain sensitive information endangering the security of the PKI when intercepted. However, it might be possible for an eavesdropper to utilize the available information to gather confidential technical or business-critical information. Therefore, users should consider protection of confidentiality on lower levels of the protocol stack, e.g., by using TLS [[RFC8446](#)], DTLS [[RFC9147](#)], or IPsec [[RFC7296](#)][[RFC4303](#)].

4. Assumptions and Restrictions

4.1. End Entity Initialization

The first step for an EE in dealing with PKI management entities is to request information about the PKI functions supported and to securely acquire a copy of the relevant root CA public key(s).

4.2. Initial Registration/Certification

There are many schemes that can be used to achieve initial registration and certification of EEs. No one method is suitable for all situations due to the range of policies that a CA may implement and the variation in the types of EE that can occur.

However, we can classify the initial registration/certification schemes that are supported by this specification. Note that the word "initial", above, is crucial: We are dealing with the situation where the EE in question has had no previous contact with the PKI, except having received the root CA certificate of that PKI by some zero-touch method like BRSKI [RFC8995] [RFC9733] or SZTP [RFC8572]. In case the EE already possesses certified keys, then some simplifications/alternatives are possible.

Having classified the schemes that are supported by this specification, we can then specify some as mandatory and some as optional. The goal is that the mandatory schemes cover a sufficient number of the cases that will arise in real use, whilst the optional schemes are available for special cases that arise less frequently. In this way, we achieve a balance between flexibility and ease of implementation.

Further classification of mandatory and optional schemes addressing different environments is available, e.g., in Appendices C and D of this specification on managing human user certificates as well as in the Lightweight CMP Profile [RFC9483] on fully automating certificate management in a machine-to-machine and Internet of Things (IoT) environment. Industry standards such as [ETSI-3GPP.33.310] for mobile networks and [UNISIG.Subset-137] for railroad automation have adopted CMP and defined a series of mandatory schemes for their use cases.

We will now describe the classification of initial registration/certification schemes.

4.2.1. Criteria Used

4.2.1.1. Initiation of Registration/Certification

In terms of the PKI messages that are produced, we can regard the initiation of the initial registration/certification exchanges as occurring wherever the first PKI message relating to the EE is produced. Note that the real-world initiation of the registration/certification procedure may occur elsewhere (e.g., a personnel department may telephone an RA operator or use zero-touch methods like BRSKI [RFC8995] or SZTP [RFC8572]).

The possible locations are at the EE, an RA, or a CA.

4.2.1.2. End Entity Message Origin Authentication

The online messages produced by the EE that requires a certificate may be authenticated or not. The requirement here is to authenticate the origin of any messages from the EE to the PKI (CA/RA).

In this specification, such authentication is achieved by two different means:

- symmetric: The PKI (CA/RA) issuing the EE with a secret value (initial authentication key) and reference value (used to identify the secret value) via some out-of-band means. The initial authentication key can then be used to protect relevant PKI messages.
- asymmetric: Using a private key and certificate issued by another PKI trusted for initial authentication, e.g., an Initial Device Identifier (IDevID) [IEEE 802.1AR](#) [[IEEE.802.1AR-2018](#)]. The trust establishment in this external PKI is out of scope of this document.

Thus, we can classify the initial registration/certification scheme according to whether or not the online 'end entity -> PKI management entity' messages are authenticated or not.

Note 1: We do not discuss the authentication of the 'PKI management entity -> end entity' messages here, as this is always **REQUIRED**. In any case, it can be achieved simply once the root-CA public key has been installed at the EE's equipment or it can be based on the initial authentication key.

Note 2: An initial registration/certification procedure can be secure where the messages from the EE are authenticated via some out-of-band means (e.g., a subsequent visit).

4.2.1.3. Location of Key Generation

In this specification, "key generation" is regarded as occurring wherever either the public or private component of a key pair first occurs in a PKIMessage. Note that this does not preclude a centralized key generation service by a KGA; the actual key pair **MAY** have been generated elsewhere and transported to the EE, RA, or CA using a (proprietary or standardized) key generation request/response protocol (outside the scope of this specification).

Thus, there are three possibilities for the location of "key generation": the EE, a KGA, or a CA.

4.2.1.4. Confirmation of Successful Certification

Following the creation of a certificate for an EE, additional assurance can be gained by having the EE explicitly confirm successful receipt of the message containing (or indicating the creation of) the certificate. Naturally, this confirmation message must be protected (based on the initial symmetric or asymmetric authentication key or other means).

This gives two further possibilities: confirmed or not.

4.2.2. Initial Registration/Certification Schemes

The criteria above allow for a large number of initial registration/certification schemes. Examples of possible initial registration/certification schemes can be found in the following subsections. An entity may support other schemes specified in profiles of PKIX-CMP, such as Appendices [C](#) and [D](#) or [[RFC9483](#)].

4.2.2.1. Centralized Scheme

In terms of the classification above, this scheme is, in some ways, the simplest possible, where:

- initiation occurs at the certifying CA;
- no online message authentication is required;
- "key generation" occurs at the certifying CA (see [Section 4.2.1.3](#)); and
- no confirmation message is required.

In terms of message flow, this scheme means that the only message required is sent from the CA to the EE. The message must contain the entire TEE for the EE. Some out-of-band means must be provided to allow the EE to authenticate the message received and to decrypt any encrypted values.

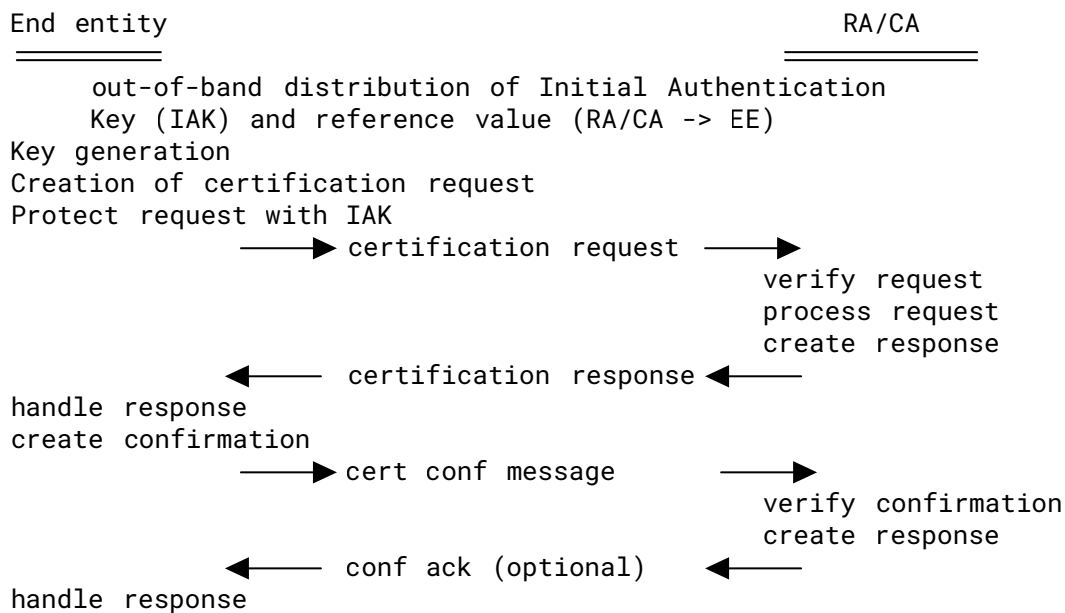
4.2.2.2. Basic Authenticated Scheme

In terms of the classification above, this scheme is where:

- initiation occurs at the EE;
- message authentication is required;
- "key generation" occurs at the EE (see [Section 4.2.1.3](#)); and
- a confirmation message is recommended.

Note: An Initial Authentication Key (IAK) can be either a symmetric key or an asymmetric private key with a certificate issued by another PKI trusted for this purpose. The establishment of such trust is out of scope of this document.

In terms of message flow, the basic authenticated scheme is as follows:



Note: Where verification of the cert confirmation message fails, the RA/CA **MUST** revoke the newly issued certificate if it has been published or otherwise made available.

4.3. POP of Private Key

POP is where a PKI management entity (CA/RA) verifies if an EE has access to the private key corresponding to a given public key. The question of whether, and in what circumstances, POPs add value to a PKI is a debate as old as PKI itself! See [Section 8.1](#) for a further discussion on the necessity of POP in PKI.

The PKI management operations specified here make it possible for an EE to prove to a CA/RA that it has possession of (i.e., is able to use) the private key corresponding to the public key for which a certificate is requested (see [Section 5.2.8](#) for different POP methods). A given CA/RA is free to choose how to enforce POP (e.g., out-of-band procedural means versus PKIX-CMP in-band messages) in its certification exchanges (i.e., this may be a policy issue). However, it is **REQUIRED** that CAs/RAs **MUST** enforce POP by some means because there are currently many non-PKIX operational protocols in use (various electronic mail protocols are one example) that do not explicitly check the binding between the EE and the private key. Until operational protocols that do verify the binding (for signature, encryption, key agreement, and KEM key pairs) exist, and are ubiquitous, this binding can only be assumed to have been verified by the CA/RA. Therefore, if the binding is not verified by the CA/RA, certificates in the Internet PKI end up being somewhat less meaningful.

POP is accomplished in different ways depending upon the type of key for which a certificate is requested. If a key can be used for multiple purposes (e.g., an RSA key), then any appropriate method **MAY** be used (e.g., a key that may be used for signing, as well as other purposes, **MUST NOT** be sent to the CA/RA in order to prove possession unless archival of the private key is explicitly desired).

This specification explicitly allows for cases where an EE supplies the relevant proof to an RA and the RA subsequently attests to the CA that the required proof has been received (and validated!). For example, an EE wishing to have a signing key certified could send the appropriate signature to the RA, which then simply notifies the relevant CA that the EE has supplied the required proof. Of course, such a situation may be disallowed by some policies (e.g., CAs may be the only entities permitted to verify POP during certification).

4.3.1. Signature Keys

For signature keys, the EE can sign a value to prove possession of the private key; see [Section 5.2.8.2](#).

4.3.2. Encryption Keys

For encryption keys, the EE can provide the private key to the CA/RA (e.g., for archiving), see [Section 5.2.8.3.1](#), or can be required to decrypt a value in order to prove possession of the private key. Decrypting a value can be achieved either directly (see [Section 5.2.8.3.3](#)) or indirectly (see [Section 5.2.8.3.2](#)).

The direct method is for the RA/CA to issue a random challenge to which an immediate response by the EE is required.

The indirect method is to issue a certificate that is encrypted for the EE (and have the EE demonstrate its ability to decrypt this certificate in the confirmation message). This allows a CA to issue a certificate in a form that can only be used by the intended EE.

This specification encourages use of the indirect method because it requires no extra messages to be sent (i.e., the proof can be demonstrated using the {request, response, confirmation} triple of messages).

4.3.3. Key Agreement Keys

For key agreement keys, the EE and the PKI management entity (i.e., CA or RA) must establish a shared secret key in order to prove that the EE has possession of the private key.

Note that this need not impose any restrictions on the keys that can be certified by a given CA. In particular, for Diffie-Hellman (DH) keys, the EE may freely choose its algorithm parameters provided that the CA can generate a short-term (or one-time) key pair with the appropriate parameters when necessary.

4.3.4. KEM Keys

For KEM keys, the EE can provide the private key to the CA/RA (e.g., for archiving), see [Section 5.2.8.3.1](#), or can be required to decrypt a value in order to prove possession of the private key. Decrypting a value can be achieved either directly (see [Section 5.2.8.3.3](#)) or indirectly (see [Section 5.2.8.3.2](#)).

Note: A definition of KEMs can be found in [Section 1](#) of [RFC9629].

The direct method is for the RA/CA to issue a random challenge to which an immediate response by the EE is required.

The indirect method is to issue a certificate that is encrypted for the EE using a shared secret key derived from a key encapsulated using the public key (and have the EE demonstrate its ability to use its private key for decapsulation of the KEM ciphertext, derive the shared secret key, decrypt this certificate, and provide a hash of the certificate in the confirmation message). This allows a CA to issue a certificate in a form that can only be used by the intended EE.

This specification encourages use of the indirect method because it requires no extra messages to be sent (i.e., the proof can be demonstrated using the {request, response, confirmation} triple of messages).

A certification request message for a KEM certificate **SHALL** use POPOPrivKey by using the keyEncipherment choice of ProofOfPossession (see [Section 5.2.8](#)) in the popo field of CertReqMsg as long as no KEM-specific choice is available.

4.4. Root CA Key Update

This discussion only applies to CAs that are directly trusted by some EEs. Recognizing whether a self-signed or non-self-signed CA is supposed to be directly trusted for some EEs is a matter of CA policy and EE configuration. Thus, this is beyond the scope of this document.

The basis of the procedure described here is that the CA protects its new public key using its previous private key and vice versa. Thus, when a CA updates its key pair, it may generate two link certificates: "old with new" and "new with old".

Note: The usage of link certificates has been shown to be very specific for each use case, and no assumptions are done on this aspect. RootCaKeyUpdateContent is updated to specify these link certificates as optional.

Note: When an LDAP directory is used to publish root CA updates, the old and new root CA certificates together with the two link certificates are stored as cACertificate attribute values.

When a CA changes its key pair, those entities who have acquired the old CA public key via "out-of-band" means are most affected. These EEs need to acquire the new CA public key in a trusted way. This may be achieved "out-of-band" by using a repository or by using online messages also containing the link certificates "new with old". Once the EE acquired and properly verified the new CA public key, it must load the new trust anchor information into its trusted store.

The data structure used to protect the new and old CA public keys is typically a standard X.509v3 certificate (which may also contain extensions). There are no new data structures required.

Note: Sometimes self-signed root CA certificates do not make use of X.509v3 extensions and may be X.509v1 certificates. Therefore, a root CA key update must be able to work for version 1 certificates. The use of the X.509v3 KeyIdentifier extension is recommended for easier path building.

Note: While the scheme could be generalized to cover cases where the CA updates its key pair more than once during the validity period of one of its EEs' certificates, this generalization seems of dubious value. Not having this generalization simply means that the validity periods of certificates issued with the old CA key pair cannot exceed the end of the "old with new" certificate validity period.

Note: This scheme offers a mechanism to ensure that EEs will acquire the new CA public key, at the latest by the expiry of the last certificate they owned that was signed with the old CA private key. Certificate and/or key update operations occurring at other times do not necessarily require this (depending on the EE's equipment).

Note: In practice, a new root CA may have a slightly different subject Distinguished Name (DN), e.g., indicating a generation identifier like the year of issuance or a version number, for instance, in an Organizational Unit (OU) element. How to bridge trust to the new root CA certificate in a CA DN change or a cross-certificate scenario is out of scope for this document.

4.4.1. CA Operator Actions

To change the key of the CA, the CA operator does the following:

1. Generate a new key pair.
2. Create a certificate containing the new CA public key signed with the new private key or by the private key of some other CA (the "new with new" certificate).
3. Optionally: Create a link certificate containing the new CA public key signed with the old private key (the "new with old" certificate).
4. Optionally: Create a link certificate containing the old CA public key signed with the new private key (the "old with new" certificate).
5. Publish these new certificates so that EEs may acquire it, e.g., using a repository or RootCaKeyUpdateContent.

The old CA private key is then no longer required when the validity of the "old with old" certificate ended. However, the old CA public key will remain in use for validating the "new with old" link certificate until the new CA public key is loaded into the trusted store. The old CA public key is no longer required (other than for non-repudiation) when all EEs of this CA have securely acquired and stored the new CA public key.

The "new with new" certificate must have a validity period with a notBefore time that is before the notAfter time of the "old with old" certificate and a notAfter time that is after the notBefore time of the next update of this certificate.

The "new with old" certificate must have a validity period with the same notBefore time as the "new with new" certificate and a notAfter time by which all EEs of this CA will securely possess the new CA public key (at the latest, at the notAfter time of the "old with old" certificate).

The "old with new" certificate must have a validity period with the same notBefore and notAfter time as the "old with old" certificate.

Note: Further operational considerations on transition from one root CA self-signed certificate to the next is available in [Section 5](#) of [RFC8649].

4.4.2. Verifying Certificates

Normally when verifying a signature, the verifier verifies (among other things) the certificate containing the public key of the signer. However, once a CA is allowed to update its key, there are a range of new possibilities. These are shown in the table below.

	Verifier's TEE contains NEW public key	Verifier's TEE contains OLD public key
Signer's certificate is protected using NEW key pair	Case 1: The verifier can directly verify the certificate.	Case 2: The verifier is missing the NEW public key.
Signer's certificate is protected using OLD key pair	Case 3: The verifier is missing the OLD public key.	Case 4: The verifier can directly verify the certificate.

Table 1

4.4.2.1. Verification in Cases 1 and 4

In these cases, the verifier has a local copy of the CA public key that can be used to verify the certificate directly. This is the same as the situation where no key change has occurred.

4.4.2.2. Verification in Case 2

In case 2, the verifier must get access to the new public key of the CA. Case 2 will arise when the CA operator has issued the verifier's certificate, then changed the CA's key, and then issued the signer's certificate; so it is quite a typical case.

The verifier does the following:

1. Get the "new with new" and "new with old" certificates. The location of where to retrieve these certificates may be available in the authority information access extension of the "old with old" certificate (see the access method for caIssuers in [Section 4.2.2.1](#) of [RFC5280]), or it may be locally configured.
 - a. If a repository is available, look up the certificates in the caCertificate attribute.
 - b. If an HTTP or FTP server is available, pick the certificates from the "certs-only" CMS message.

- c. If a CMP server is available, request the certificates using the root CA update the general message (see [Section 5.3.19.15](#)).
 - d. Otherwise, get the certificates "out-of-band" using any trustworthy mechanism.
2. If the certificates are received, check that the validity periods and the subject and issuer fields match. Verify the signatures using the old root CA key (which the verifier has locally).
 3. If all checks are successful, securely store the new trust anchor information and validate the signer's certificate.

4.4.2.3. Verification in Case 3

In case 3, the verifier must get access to the old public key of the CA. Case 3 will arise when the CA operator has issued the signer's certificate, then changed the key, and then issued the verifier's certificate.

The verifier does the following:

1. Get the "old with new" certificate. The location of where to retrieve these certificates may be available in the authority information access extension of the "new with new" certificate (see caIssuers access method in [Section 4.2.2.1](#) of [\[RFC5280\]](#)), or it may be locally configured.
 - a. If a repository is available, look up the certificate in the caCertificate attribute.
 - b. If an HTTP or FTP server is available, pick the certificate from the "certs-only" CMS message.
 - c. If a CMP server and an untrusted copy of the old root CA certificate are available (e.g., the signer provided it in-band in the CMP extraCerts filed), request the certificate using the root CA update the general message (see [Section 5.3.19.15](#)).
 - d. Otherwise, get the certificate "out-of-band" using any trustworthy mechanism.
2. If the certificate is received, check that the validity periods and the subject and issuer fields match. Verify the signatures using the new root CA key (which the verifier has locally).
3. If all checks were successful, securely store the old trust anchor information and validate the signer's certificate.

4.4.3. Revocation - Change of the CA Key

As we saw above, the verification of a certificate becomes more complex once the CA is allowed to change its key. This is also true for revocation checks, as the CA may have signed the CRL using a newer private key than the one within the user's TEE.

The analysis of the alternatives is the same as for certificate verification.

4.5. EKU for PKI Entities

The EKU extension indicates the purposes for which the certified key pair may be used. Therefore, it restricts the use of a certificate to specific applications.

A CA may want to delegate parts of its duties to other PKI management entities. This section provides a mechanism to both prove this delegation and enable automated means for checking the authorization of this delegation. Such delegation may also be expressed by other means, e.g., explicit configuration.

To offer automatic validation for the delegation of a role by a CA to another entity, the certificates used for CMP message protection or signed data for central key generation **MUST** be issued by the delegating CA and **MUST** contain the respective EKUs. This proves that the delegating CA authorized this entity to act in the given role, as described below.

The OIDs to be used for these EKUs are:

```
id-kp-cmcCA OBJECT IDENTIFIER ::= {
    iso(1) identified-organization(3) dod(6) internet(1)
    security(5) mechanisms(5) pkix(7) kp(3) 27 }

id-kp-cmcRA OBJECT IDENTIFIER ::= {
    iso(1) identified-organization(3) dod(6) internet(1)
    security(5) mechanisms(5) pkix(7) kp(3) 28 }

id-kp-cmKGA OBJECT IDENTIFIER ::= {
    iso(1) identified-organization(3) dod(6) internet(1)
    security(5) mechanisms(5) pkix(7) kp(3) 32 }
```

Note: [Section 2.10](#) of [\[RFC6402\]](#) specifies OIDs for a Certificate Management over CMS (CMC) CA and a CMC RA. As the functionality of a CA and RA is not specific to any protocol used for managing certificates (such as CMC or CMP), these EKUs are reused by CMP.

The meaning of the id-kp-cmKGA EKU is as follows:

CMP KGA: CMP KGAs are CAs or are identified by the id-kp-cmKGA EKU. The CMP KGA knows the private key it generated on behalf of the EE. This is a very sensitive service and needs specific authorization, which by default is with the CA certificate itself. The CA may delegate its authorization by placing the id-kp-cmKGA EKU in the certificate used to authenticate the origin of the generated private key. The authorization may also be determined through local configuration of the EE.

5. Data Structures

This section contains descriptions of the data structures required for PKI management messages. [Section 6](#) describes constraints on their values and the sequence of events for each of the various PKI management operations.

5.1. Overall PKI Message

All of the messages used in this specification for the purposes of PKI management use the following structure:

```

PKIMessage ::= SEQUENCE {
    header          PKIHeader,
    body            PKIBody,
    protection      [0] PKIProtection OPTIONAL,
    extraCerts      [1] SEQUENCE SIZE (1..MAX) OF CMPCertificate
                      OPTIONAL
}

PKIMessages ::= SEQUENCE SIZE (1..MAX) OF PKIMessage

```

The PKIHeader contains information that is common to many PKI messages.

The PKIBody contains message-specific information.

The PKIProtection, when used, contains bits that protect the PKI message.

The extraCerts field can contain certificates that may be useful to the recipient. For example, this can be used by a CA or RA to present an EE with certificates that it needs to verify its own new certificate (for example, if the CA that issued the EE's certificate is not a root CA for the EE). Note that this field does not necessarily contain a certification path; the recipient may have to sort, select from, or otherwise process the extra certificates in order to use them.

5.1.1. PKI Message Header

All PKI messages require some header information for addressing and transaction identification. Some of this information will also be present in a transport-specific envelope. However, if the PKI message is protected, then this information is also protected (i.e., we make no assumption about secure transport).

The following data structure is used to contain this information:

```

PKIHeader ::= SEQUENCE {
    pvno            INTEGER      { cmp1999(1), cmp2000(2),
                                cmp2021(3) },
    sender          GeneralName,
    recipient       GeneralName,
    messageTime     [0] GeneralizedTime OPTIONAL,
    protectionAlg   [1] AlgorithmIdentifier{ALGORITHM, {...}}
                      OPTIONAL,
    senderKID       [2] KeyIdentifier      OPTIONAL,
    recipKID        [3] KeyIdentifier      OPTIONAL,
    transactionID   [4] OCTET STRING      OPTIONAL,
    senderNonce     [5] OCTET STRING      OPTIONAL,
    recipNonce      [6] OCTET STRING      OPTIONAL,
    freeText        [7] PKIFreeText        OPTIONAL,
    generalInfo     [8] SEQUENCE SIZE (1..MAX) OF
                      InfoTypeAndValue    OPTIONAL
}

PKIFreeText ::= SEQUENCE SIZE (1..MAX) OF UTF8String

```

The usage of the protocol version number (pvno) is described in [Section 7](#).

The sender field contains the name of the sender of the PKIMessage. This name (in conjunction with senderKID, if supplied) should be sufficient to indicate the key to use to verify the protection on the message. If nothing about the sender is known to the sending entity (e.g., in the initial request message, where the EE may not know its own DN, email name, IP address, etc.), then the "sender" field **MUST** contain a "NULL-DN" value in the directoryName choice. A "NULL-DN" is a SEQUENCE OF relative DNs of zero length and is encoded as 0x3000. In such a case, the senderKID field **MUST** hold an identifier (i.e., a reference number) that indicates to the receiver the appropriate shared secret information to use to verify the message.

The recipient field contains the name of the recipient of the PKIMessage. This name (in conjunction with recipKID, if supplied) should be usable to verify the protection on the message.

The protectionAlg field specifies the algorithm used to protect the message. If no protection bits are supplied (note that PKIProtection is **OPTIONAL**), then this field **MUST** be omitted; if protection bits are supplied, then this field **MUST** be supplied.

senderKID and recipKID are usable to indicate which keys have been used to protect the message (recipKID will normally only be required where protection of the message uses DH or Elliptic Curve Diffie-Hellman (ECDH) keys). These fields **MUST** be used if required to uniquely identify a key (e.g., if more than one key is associated with a given sender name). The senderKID **SHOULD** be used in any case.

Note: The recommendation of using senderKID has changed since [\[RFC4210\]](#), where it was recommended to be omitted if not needed to identify the protection key.

The transactionID field within the message header is to be used to allow the recipient of a message to correlate this with an ongoing transaction. This is needed for all transactions that consist of more than just a single request/response pair. For transactions that consist of a single request/response pair, the rules are as follows. A client **MUST** populate the transactionID field if the message contains an infoValue of type KemCiphertextInfo (see [Section 5.1.3.4](#)). In all other cases, the client **MAY** populate the transactionID field of the request. If a server receives such a request that has the transactionID field set, then it **MUST** set the transactionID field of the response to the same value. If a server receives such request with a missing transactionID field, then it **MUST** populate the transactionID field if the message contains a KemCiphertextInfo field. In all other cases, the server **MAY** set the transactionID field of the response.

For transactions that consist of more than just a single request/response pair, the rules are as follows. If the message contains an infoValue of type KemCiphertextInfo, the client **MUST** generate a transactionID; otherwise, the client **SHOULD** generate a transactionID for the first request. If a server receives such a request that has the transactionID field set, then it **MUST** set the transactionID field of the response to the same value. If a server receives such request with a missing transactionID field, then it **MUST** populate the transactionID field of the response with a server-generated ID. Subsequent requests and responses **MUST** all set the transactionID field to the thus established value. In all cases where a transactionID is being used, a given client **MUST NOT** have more than one transaction with the same transactionID in progress at any time (to a

given server). Servers are free to require uniqueness of the transactionID or not, as long as they are able to correctly associate messages with the corresponding transaction. Typically, this means that a server will require the {client, transactionID} tuple to be unique, or even the transactionID alone to be unique, if it cannot distinguish clients based on any transport-level information. A server receiving the first message of a transaction (which requires more than a single request/response pair) that contains a transactionID that does not allow it to meet the above constraints (typically because the transactionID is already in use) **MUST** send back an ErrorMessageContent with a PKIFailureInfo of transactionIdInUse. It is **RECOMMENDED** that the clients fill the transactionID field with 128 bits of (pseudo-)random data for the start of a transaction to reduce the probability of having the transactionID in use at the server.

The senderNonce and recipNonce fields protect the PKIMessage against replay attacks. The senderNonce will typically be 128 bits of (pseudo-)random data generated by the sender, whereas the recipNonce is copied from the senderNonce field of the previous message in the transaction.

The messageTime field contains the time at which the sender created the message. This may be useful to allow EEs to correct/check their local time for consistency with the time on a central system.

The freeText field may be used to send a human-readable message to the recipient (in any number of languages). Each UTF8String **MAY** include a language tag [RFC5646] to indicate the language of the contained text. The first language used in this sequence indicates the desired language for replies.

The generalInfo field may be used to send machine-processable additional data to the recipient. The following generalInfo extensions are defined and **MAY** be supported.

5.1.1.1. ImplicitConfirm

This is used by the EE to inform the CA or RA that it does not wish to send a certificate confirmation for issued certificates.

```
id-it-implicitConfirm OBJECT IDENTIFIER ::= {id-it 13}
ImplicitConfirmValue ::= NULL
```

If the CA grants the request to the EE, it **MUST** put the same extension in the PKIHeader of the response. If the EE does not find the extension in the response, it **MUST** send the certificate confirmation.

5.1.1.2. ConfirmWaitTime

This is used by the CA or RA to inform the EE how long it intends to wait for the certificate confirmation before revoking the certificate and deleting the transaction.

```
id-it-confirmWaitTime OBJECT IDENTIFIER ::= {id-it 14}
ConfirmWaitTimeValue ::= GeneralizedTime
```

5.1.1.3. OrigPKIMessage

An RA **MAY** include the original PKIMessage from the EE in the generalInfo field of the PKIHeader of a PKIMessage. This is used by the RA to inform the CA of the original PKIMessage that it received from the EE and modified in some way (e.g., added or modified particular field values or added new extensions) before forwarding the new PKIMessage. This accommodates, for example, cases in which the CA wishes to check the message origin, the POP, or other information on the original EE message.

Note: If the changes made by the RA to the original PKIMessage break the POP of a certificate request, the RA can set the popo field of the new PKIMessage to raVerified (see [Section 5.2.8.4](#)).

Unless the OrigPKIMessage infoValue is in the header of a nested message, it **MUST** contain exactly one PKIMessage. The contents of OrigPKIMessage infoValue in the header of a nested message **MAY** contain multiple PKIMessage structures, which **MUST** be in the same order as the PKIMessage structures in PKIBody.

```
id-it-origPKIMessage OBJECT IDENTIFIER ::= {id-it 15}
OrigPKIMessageValue ::= PKIMessages
```

5.1.1.4. CertProfile

This is used by the EE to indicate specific certificate profiles, e.g., when requesting a new certificate or a certificate request template (see [Section 5.3.19.16](#)).

```
id-it-certProfile OBJECT IDENTIFIER ::= {id-it 21}
CertProfileValue ::= SEQUENCE SIZE (1..MAX) OF UTF8String
```

When used in a p10cr message, the CertProfileValue sequence **MUST NOT** contain multiple certificate profile names. When used in an ir/cr/kur/genm message, the CertProfileValue sequence **MUST NOT** contain more certificate profile names than the number of CertReqMsg or GenMsgContent InfoTypeAndValue elements contained in the message body.

The certificate profile names in the CertProfileValue sequence relate to the CertReqMsg or GenMsgContent InfoTypeAndValue elements in the given order. An empty string means no certificate profile name is associated with the respective CertReqMsg or GenMsgContent InfoTypeAndValue element. If the CertProfileValue sequence contains less certificate profile entries than CertReqMsg or GenMsgContent InfoTypeAndValue elements, the remaining CertReqMsg or GenMsgContent InfoTypeAndValue elements have no profile name associated with them.

5.1.1.5. KemCiphertextInfo

A PKI entity **MAY** provide the KEM ciphertext for MAC-based message protection using KEM (see [Section 5.1.3.4](#)) in the generalInfo field of a request message to a PKI management entity if it knows that the PKI management entity uses a KEM key pair and has its public key.

```
id-it-KemCiphertextInfo OBJECT IDENTIFIER ::= { id-it 24 }
KemCiphertextInfoValue ::= KemCiphertextInfo
```

For more details of KEM-based message protection, see [Section 5.1.3.4](#). See [Section 5.3.19.18](#) for the definition of {id-it 24}.

5.1.2. PKI Message Body

```
PKIBody ::= CHOICE {
  ir      [0] CertReqMessages,      --Initialization Req
  ip      [1] CertRepMessage,       --Initialization Resp
  cr      [2] CertReqMessages,      --Certification Req
  cp      [3] CertRepMessage,       --Certification Resp
  p10cr   [4] CertificationRequest, --PKCS #10 Cert. Req.
  popdecc [5] POPDecKeyChallContent, --pop Challenge
  popdecr [6] POPDecKeyRespContent,  --pop Response
  kur     [7] CertReqMessages,      --Key Update Request
  kup     [8] CertRepMessage,       --Key Update Response
  krr     [9] CertReqMessages,      --Key Recovery Req
  krp     [10] KeyRecRepContent,     --Key Recovery Resp
  rr      [11] RevReqContent,       --Revocation Request
  rp      [12] RevRepContent,       --Revocation Response
  ccr     [13] CertReqMessages,     --Cross-Cert. Request
  ccp     [14] CertRepMessage,      --Cross-Cert. Resp
  ckuann  [15] CAKeyUpdContent,     --CA Key Update Ann.
  cann    [16] CertAnnContent,      --Certificate Ann.
  rann    [17] RevAnnContent,       --Revocation Ann.
  crlann  [18] CRLAnnContent,       --CRL Announcement
  pkiconf [19] PKIConfirmContent,   --Confirmation
  nested  [20] NestedMessageContent, --Nested Message
  genm    [21] GenMsgContent,       --General Message
  genp    [22] GenRepContent,       --General Response
  error   [23] ErrorMsgContent,     --Error Message
  certConf [24] CertConfirmContent, --Certificate Confirm
  pollReq [25] PollReqContent,      --Polling Request
  pollRep [26] PollRepContent       --Polling Response
}
```

The specific types are described in [Section 5.3](#) below.

5.1.3. PKI Message Protection

Some PKI messages will be protected for integrity.

Note: If an asymmetric algorithm is used to protect a message and the relevant public component has been certified already, then the origin of the message can also be authenticated. On the other hand, if the public component is uncertified, then the message origin cannot be automatically authenticated but may be authenticated via out-of-band means.

When protection is applied, the following structure is used:


```
PKIProtection ::= BIT STRING
```

The input to the calculation of PKIProtection is the DER encoding of the following data structure:

```
ProtectedPart ::= SEQUENCE {  
    header    PKIHeader,  
    body      PKIBody  
}
```

There **MAY** be cases in which the PKIProtection BIT STRING is deliberately not used to protect a message (i.e., this **OPTIONAL** field is omitted) because other protection, external to PKIX, will be applied instead. Such a choice is explicitly allowed in this specification. Examples of such external protection include CMS [RFC5652] and Security Multiparts [RFC1847] encapsulation of the PKIMessage (or simply the PKIBody (omitting the CHOICE tag), if the relevant PKIHeader information is securely carried in the external mechanism). It is noted, however, that many such external mechanisms require that the EE already possesses a public-key certificate, a unique DN, and/or other such infrastructure-related information. Thus, they may not be appropriate for initial registration, key-recovery, or any other process with "bootstrapping" characteristics. For those cases, it may be necessary that the PKIProtection parameter be used. In the future, if/when external mechanisms are modified to accommodate bootstrapping scenarios, the use of PKIProtection may become rare or non-existent.

Depending on the circumstances, the PKIProtection bits may contain a MAC or signature. Only the following cases can occur:

5.1.3.1. Shared Secret Information

In this case, the sender and recipient share secret information with sufficient entropy (established via out-of-band means). PKIProtection will contain a MAC value, and the protectionAlg **MAY** be one of the options described in Section 6.1 of CMP Algorithms [RFC9481].

The algorithm identifier id-PasswordBasedMac is defined in Section 4.4 of [RFC4211] and updated by [RFC9045]. It is mentioned in Section 6.1.1 of [RFC9481] for backward compatibility. More modern alternatives are listed in Section 6.1 of [RFC9481].

```
id-PasswordBasedMac OBJECT IDENTIFIER ::= {1 2 840 113533 7 66 13}  
PBMPParameter ::= SEQUENCE {  
    salt          OCTET STRING,  
    owf           AlgorithmIdentifier,  
    iterationCount INTEGER,  
    mac           AlgorithmIdentifier  
}
```

The following text gives a method of key expansion to be used when the MAC algorithm requires an input length that is larger than the size of the one-way function (OWF).

Note: [Section 4.4](#) of [\[RFC4211\]](#) and [\[RFC9045\]](#) do not mention this key expansion method or give an example using HMAC algorithms where key expansion is not needed. It is recognized that this omission in [\[RFC4211\]](#) can lead to confusion and possible incompatibility if key expansion [\[RFC4210\]](#) is not used when needed. Therefore, when key expansion is required (when $K > H$), the key expansion defined in the following text **MUST** be used.

In the above protectionAlg, the salt value is appended to the shared secret input. The OWF is then applied iterationCount times, where the salted secret is the input to the first iteration and, for each successive iteration, the input is set to be the output of the previous iteration. The output of the final iteration (called "BASEKEY" for ease of reference, with a size of "H") is what is used to form the symmetric key. If the MAC algorithm requires a K-bit key and $K \leq H$, then the most significant K bits of BASEKEY are used. If $K > H$, then all of BASEKEY is used for the most significant H bits of the key, OWF("1" || BASEKEY) is used for the next most significant H bits of the key, OWF("2" || BASEKEY) is used for the next most significant H bits of the key, and so on, until all K bits have been derived. [Here "N" is the ASCII byte encoding the number N and "||" represents concatenation.]

Note: It is **RECOMMENDED** that the fields of PBMPParameter remain constant throughout the messages of a single transaction (e.g., ir/ip/certConf/pkiConf) to reduce the overhead associated with PasswordBasedMac computation.

5.1.3.2. DH Key Pairs

Where the sender and receiver possess finite-field or elliptic-curve-based DH certificates with compatible DH parameters in order to protect the message, the EE must generate a symmetric key based on its private DH key value and the DH public key of the recipient of the PKI message. PKIProtection will contain a MAC value keyed with this derived symmetric key, and the protectionAlg will be the following:

```
id-DHBasedMac OBJECT IDENTIFIER ::= {1 2 840 113533 7 66 30}

DHBMParameter ::= SEQUENCE {
    owf                AlgorithmIdentifier,
    -- AlgId for an OWF
    mac                AlgorithmIdentifier
    -- the MAC AlgId
}
```

In the above protectionAlg, OWF is applied to the result of the DH computation. The OWF output (called "BASEKEY" for ease of reference, with a size of "H") is what is used to form the symmetric key. If the MAC algorithm requires a K-bit key and $K \leq H$, then the most significant K bits of BASEKEY are used. If $K > H$, then all of BASEKEY is used for the most significant H bits of the key, OWF("1" || BASEKEY) is used for the next most significant H bits of the key, OWF("2" || BASEKEY) is used for the next most significant H bits of the key, and so on, until all K bits have been derived. [Here "N" is the ASCII byte encoding the number N and "||" represents concatenation.]

Note: Hash algorithms that can be used as OWFs are listed in [Section 2](#) of CMP Algorithms [\[RFC9481\]](#).

5.1.3.3. Signature

In this case, the sender possesses a signature key pair and simply signs the PKI message. PKIProtection will contain the signature value and the protectionAlg will be an AlgorithmIdentifier for a digital signature, which **MAY** be one of the options described in [Section 3](#) of CMP Algorithms [\[RFC9481\]](#).

5.1.3.4. Key Encapsulation

In case the sender of a message has a KEM key pair, it can be used to establish a shared secret key for MAC-based message protection. This can be used for message authentication.

This approach uses the definition of KEM algorithm functions in [Section 1](#) of [\[RFC9629\]](#) as follows:

A KEM algorithm provides three functions:

1. KeyGen() -> (pk, sk): Generate a public key (pk) and a private (secret) key (sk).
2. Encapsulate(pk) -> (ct, ss): Given the public key (pk), produce a ciphertext (ct) and a shared secret (ss).
3. Decapsulate(sk, ct) -> (ss): Given the private key (sk) and the ciphertext (ct), produce the shared secret (ss).

To support a particular KEM algorithm, the PKI entity that possesses a KEM key pair and wishes to use it for MAC-based message protection **MUST** support the KEM Decapsulate() function. The PKI entity that wishes to verify the MAC-based message protection **MUST** support the KEM Encapsulate() function. The respective public KEM key is usually carried in a certificate [\[ML-KEM\]](#).

Note: Both PKI entities send and receive messages in a PKI management operation. Both PKI entities may independently wish to protect messages using their KEM key pairs. For ease of explanation, we use the terms "Alice" to denote the PKI entity possessing the KEM key pair and who wishes to provide MAC-based message protection and "Bob" to denote the PKI entity having Alice's authentic public KEM key and who needs to verify the MAC-based protection provided by Alice.

Assuming Bob has Alice's KEM public key, he generates the ciphertext using KEM encapsulation and transfers it to Alice in an InfoTypeAndValue structure. Alice then retrieves the KEM shared secret from the ciphertext using KEM decapsulation and the associated KEM private key. Using a key derivation function (KDF), Alice derives a shared secret key from the KEM shared secret and other data sent by Bob. PKIProtection will contain a MAC value calculated using that shared secret key, and the protectionAlg will be the following:

```
id-KemBasedMac OBJECT IDENTIFIER ::= {1 2 840 113533 7 66 16}

KemBMPParameter ::= SEQUENCE {
    kdf          AlgorithmIdentifier{KEY-DERIVATION, {...}},
    kemContext   [0] OCTET STRING OPTIONAL,
    len          INTEGER (1..MAX),
    mac          AlgorithmIdentifier{MAC-ALGORITHM, {...}}
}
```

Note: The OID for id-KemBasedMac was assigned on the private-use arc { iso(1) member-body(2) us(840) nortelnetworks(113533) entrust(7) } and not assigned on an IANA-owned arc because the authors wished to place it on the same branch as the existing OIDs for id-PasswordBasedMac and id-DHBasedMac.

kdf is the algorithm identifier of the chosen KDF, and any associated parameters, used to derive the shared secret key.

kemContext **MAY** be used to transfer additional algorithm-specific context information (see also the definition of ukm in [Section 3](#) of [\[RFC9629\]](#)).

len is the output length of the KDF and **MUST** be the desired size of the key to be used for MAC-based message protection.

mac is the algorithm identifier of the chosen MAC algorithm, and any associated parameters, used to calculate the MAC value.

The KDF and MAC algorithms **MAY** be chosen from the options in CMP Algorithms [\[RFC9481\]](#).

The InfoTypeAndValue transferring the KEM ciphertext uses OID id-it-KemCiphertextInfo. It contains a KemCiphertextInfo structure, as defined in [Section 5.3.19.18](#).

Note: This InfoTypeAndValue can be carried in a genm/genp message body, as specified in [Section 5.3.19.18](#), or in the generalInfo field of PKIHeader in messages of other types (see [Section 5.1.1.5](#)).

In the following, a generic message flow for MAC-based protection using KEM is specified in more detail. It is assumed that Bob possesses Alice's public KEM key. Alice can be the initiator of a PKI management operation or the responder. For more detailed figures, see [Appendix E](#).

Generic Message Flow:

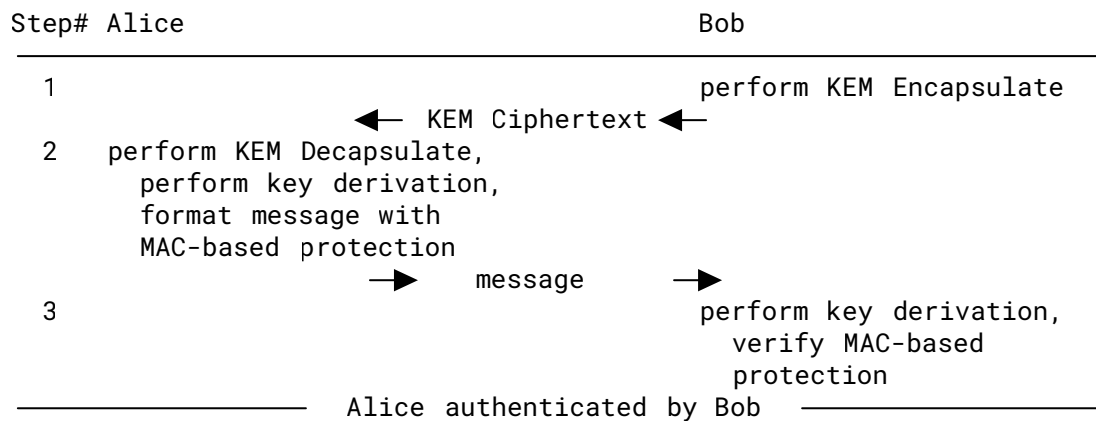


Figure 2: Generic Message Flow When Alice Has a KEM Key Pair

1. Bob needs to possess Alice's authentic public KEM key (pk), for instance, contained in a KEM certificate that was received and successfully validated by Bob beforehand.

Bob generates a shared secret (ss) and the associated ciphertext (ct) using the KEM Encapsulate function with Alice's public KEM key (pk). Bob **MUST NOT** reuse the ss and ct for other PKI management operations. From this data, Bob produces a `KemCiphertextInfo` structure, including the KEM algorithm identifier and the ciphertext (ct) and sends it to Alice in an `InfoTypeAndValue` structure, as defined in [Section 5.3.19.18](#).

Encapsulate(pk) -> (ct, ss)

2. Alice decapsulates the shared secret (ss) from the ciphertext (ct) using the KEM Decapsulate function and its private KEM key (sk).

Decapsulate(ct, sk) -> (ss)

If the decapsulation operation outputs an error, any `failInfo` field in an error response message **SHALL** contain the value `badMessageCheck` and the PKI management operation **SHALL** be terminated.

Alice derives the shared secret key (ssk) using a KDF. The shared secret (ss) is used as input key material for the KDF, and the value `len` is the desired output length of the KDF as required by the MAC algorithm to be used for message protection. KDF, `len`, and MAC will be transferred to Bob in the `protectionAlg` `KemBMPParameter`. The DER-encoded `KemOtherInfo` structure, as defined below, is used as context for the KDF.

KDF(ss, len, context)->(ssk)

The shared secret key (ssk) is used for MAC-based protection by Alice.

3. Bob derives the same shared secret key (ssk) using the KDF. Also here, the shared secret (ss) is used as input key material for the KDF, the value `len` is the desired output length for the KDF, and the DER-encoded `KemOtherInfo` structure constructed in the same way as on Alice's side is used as context for the KDF.

KDF(ss, len, context)->(ssk)

Bob uses the shared secret key (ssk) for verifying the MAC-based protection of the message received and in this way authenticates Alice.

This shared secret key (ssk) can be reused by Alice for MAC-based protection of further messages sent to Bob within the current PKI management operation.

This approach employs the notation of KDF(IKM, L, info) as described in [Section 5](#) of [\[RFC9629\]](#) with the following changes:

- IKM is the input key material. It is the symmetric secret called "ss" resulting from the KEM.
- L is dependent of the MAC algorithm that is used with the shared secret key for CMP message protection and is called "len" in this document.
- info is an additional input to the KDF, is called "context" in this document, and contains the DER-encoded KemOtherInfo structure defined as:

```
KemOtherInfo ::= SEQUENCE {  
    staticString      PKIFreeText,  
    transactionID     OCTET STRING,  
    kemContext        [0] OCTET STRING OPTIONAL  
}
```

staticString **MUST** be "CMP-KEM".

transactionID **MUST** be the value from the message containing the ciphertext (ct) in KemCiphertextInfo.

Note: The transactionID is used to ensure domain separation of the derived shared secret key between different PKI management operations. For all PKI management operations with more than one exchange, the transactionID **MUST** be set anyway (see [Section 5.1.1](#)). In case Bob provided an infoValue of type KemCiphertextInfo to Alice in the initial request message (see [Figure 4](#) of [Appendix E](#)), the transactionID **MUST** be set by Bob.

kemContext **MAY** contain additional algorithm-specific context information.

- OKM is the output keying material of the KDF used for MAC-based message protection of length len and is called "ssk" in this document.

There are various ways that Alice can request and Bob can provide the KEM ciphertext (see [Appendix E](#) for details). The KemCiphertextInfo can be requested using PKI general messages, as described in [Section 5.3.19.18](#). Alternatively, the generalInfo field of the PKIHeader can be used to convey the same request and response InfoTypeAndValue structures, as described in [Section 5.1.1.5](#). The procedure also works without Alice explicitly requesting the KEM ciphertext in case Bob knows one of Alice's KEM keys beforehand and can expect that she is ready to use it.

If both the initiator and responder in a PKI management operation have KEM key pairs, this procedure can be applied by both entities independently, establishing and using different shared secret keys for either direction.

5.1.3.5. Multiple Protection

When receiving a protected PKI message, a PKI management entity, such as an RA, **MAY** forward that message adding its own protection. Additionally, multiple PKI messages **MAY** be aggregated. There are several use cases for such messages.

- The RA confirms having validated and authorized a message and forwards the original message unchanged.
- A PKI management entity collects several messages that are to be forwarded in the same direction and forwards them in a batch. Request messages can be transferred as a batch upstream (towards the CA); response or announce messages can be transferred as a batch downstream (towards an RA but not to the EE). For instance, this can be used when bridging an offline connection between two PKI management entities.

These use cases are accomplished by nesting the messages within a new PKI message. The structure used is as follows:

```
NestedMessageContent ::= PKIMessages
```

In case an RA needs to modify a request message, it **MAY** include the original PKIMessage in the `generalInfo` field of the modified message, as described in [Section 5.1.1.3](#).

5.2. Common Data Structures

Before specifying the specific types that may be placed in a PKIBody, we define some data structures that are used in more than one case.

5.2.1. Requested Certificate Contents

Various PKI management messages require that the originator of the message indicate some of the fields that are required to be present in a certificate. The `CertTemplate` structure allows an EE or RA to specify as many data fields as the structure wishes for the requested certificate. The structure also allows an EE or RA to include any other necessary data, such as the `publicKey` field, when it is required for the certificate. A `CertTemplate` structure is identical to a `TBSCertificate` structure (see [\[RFC5280\]](#)) but with all fields optional/situational.

Note: Even if the originator completely specifies the contents of a certificate it requires, a CA is free to modify fields within the certificate actually issued. If the modified certificate is unacceptable to the requester, the requester **MUST** send back a `certConf` message that either does not include this certificate (via a `CertHash`) or does include this certificate (via a `CertHash`) along with a status of "rejected". See [Section 5.3.18](#) for the definition and use of `CertHash` and the `certConf` message.

Note: Before requesting a new certificate, an EE can request a `certTemplate` structure as a kind of certificate request blueprint in order to learn which data the CA expects to be present in the certificate request (see [Section 5.3.19.16](#)).

See CRMF [RFC4211] for CertTemplate syntax.

If certTemplate is an empty SEQUENCE (i.e., all fields omitted), then the controls field in the CertRequest structure **MAY** contain the id-regCtrl-altCertTemplate control, specifying a template for a certificate other than an X.509v3 public-key certificate. Conversely, if certTemplate is not empty (i.e., at least one field is present), then controls **MUST NOT** contain id-regCtrl-altCertTemplate. The new control is defined as follows:

```
id-regCtrl-altCertTemplate OBJECT IDENTIFIER ::= { iso(1)
  identified-organization(3) dod(6) internet(1) security(5)
  mechanisms(5) pkix(7) pkix(5) regCtrl(1) 7 }
```

```
AltCertTemplate ::= AttributeTypeAndValue
```

Also see [RFC4212] for more details on how to manage certificates in alternative formats using CRMF [RFC4211] syntax.

5.2.2. Encrypted Values

When encrypted data like a private key, certificate, POP challenge, or revocation passphrase is sent in PKI messages, it is **RECOMMENDED** to use the EnvelopedData structure. In some cases, this is accomplished by using the EncryptedKey data structure instead of EncryptedValue.

```
EncryptedKey ::= CHOICE {
  encryptedValue      EncryptedValue, -- deprecated
  envelopedData       [0] EnvelopedData }
```

See Certificate Request Message Format (CRMF) [RFC4211] for EncryptedKey and EncryptedValue syntax and Cryptographic Message Syntax (CMS) [RFC5652] for EnvelopedData syntax. Using the EncryptedKey data structure offers the choice to either use EncryptedValue (for backward compatibility only) or EnvelopedData. The use of the EncryptedValue structure has been deprecated in favor of the EnvelopedData structure. Therefore, it is **RECOMMENDED** to use EnvelopedData.

Note: The EncryptedKey structure defined in CRMF [RFC4211] is used here, which makes the update backward compatible. Using the new syntax with the untagged default choice EncryptedValue is bits-on-the-wire compatible with the old syntax.

To indicate support for EnvelopedData, the pvno cmp2021 has been introduced. Details on the usage of the pvno are described in [Section 7](#).

The EnvelopedData structure is **RECOMMENDED** to be used in CMP to transport a private key, certificate, POP challenge, or revocation passphrase in encrypted form as follows:

- It contains only one RecipientInfo structure because the content is encrypted only for one recipient.

- It may contain a private key in the AsymmetricKeyPackage structure (which is placed in the encryptedContentInfo field), as defined in [RFC5958], that is wrapped in a SignedData structure, as specified in Section 5 of [RFC5652] and [RFC8933], signed by the KGA or CA.
- It may contain a certificate, POP challenge, or revocation passphrase directly in the encryptedContent field.

The content of the EnvelopedData structure, as specified in Section 6 of [RFC5652], **MUST** be encrypted using a newly generated symmetric content-encryption key. This content-encryption key **MUST** be securely provided to the recipient using one of four key management techniques.

The choice of the key management technique to be used by the sender depends on the credential available at the recipient:

- recipient's certificate with an algorithm identifier and a public key that supports key transport and where any given key usage extension allows keyEncipherment: The content-encryption key will be protected using the key transport key management technique, as specified in Section 6.2.1 of [RFC5652].
- recipient's certificate with an algorithm identifier and a public key that supports key agreement and where any given key usage extension allows keyAgreement: The content-encryption key will be protected using the key agreement key management technique, as specified in Section 6.2.2 of [RFC5652].
- a password or shared secret: The content-encryption key will be protected using the password-based key management technique, as specified in Section 6.2.4 of [RFC5652].
- recipient's certificate with an algorithm identifier and a public key that supports KEM and where any given key usage extension allows keyEncipherment: The content-encryption key will be protected using the key management technique for KEM keys, as specified in [RFC9629].

Note: There are cases where the algorithm identifier, the type of the public key, and the key usage extension will not be sufficient to decide on the key management technique to use, e.g., when rsaEncryption is the algorithm identifier. In such cases, it is a matter of local policy to decide.

5.2.3. Status Codes and Failure Information for PKI Messages

All response messages will include some status information. The following values are defined.

```
PKIStatus ::= INTEGER {  
    accepted           (0),  
    grantedWithMods    (1),  
    rejection          (2),  
    waiting            (3),  
    revocationWarning  (4),  
    revocationNotification (5),  
    keyUpdateWarning   (6)  
}
```

Responders may use the following syntax to provide more information about failure cases.

```
PKIFailureInfo ::= BIT STRING {
    badAlg                (0),
    badMessageCheck       (1),
    badRequest             (2),
    badTime               (3),
    badCertId             (4),
    badDataFormat         (5),
    wrongAuthority        (6),
    incorrectData         (7),
    missingTimeStamp      (8),
    badPOP                (9),
    certRevoked           (10),
    certConfirmed         (11),
    wrongIntegrity        (12),
    badRecipientNonce     (13),
    timeNotAvailable      (14),
    unacceptedPolicy      (15),
    unacceptedExtension   (16),
    addInfoNotAvailable   (17),
    badSenderNonce       (18),
    badCertTemplate       (19),
    signerNotTrusted      (20),
    transactionIdInUse    (21),
    unsupportedVersion    (22),
    notAuthorized         (23),
    systemUnavail         (24),
    systemFailure         (25),
    duplicateCertReq      (26)
}

PKIStatusInfo ::= SEQUENCE {
    status      PKIStatus,
    statusString PKIFreeText    OPTIONAL,
    failInfo    PKIFailureInfo OPTIONAL
}
```

5.2.4. Certificate Identification

In order to identify particular certificates, the CertId data structure is used.

See [\[RFC4211\]](#) for CertId syntax.

5.2.5. Out-of-Band Root CA Public Key

Each root CA that provides a self-signed certificate must be able to publish its current public key via some "out-of-band" means or together with the respective link certificate using an online mechanism. While such mechanisms are beyond the scope of this document, we define data structures that can support such mechanisms.

There are generally two methods available: Either the CA directly publishes its self-signed certificate, or this information is available via the directory (or equivalent) and the CA publishes a hash of this value to allow verification of its integrity before use.

Note: As an alternative to out-of-band distribution of root CA public keys, the CA can provide the self-signed certificate together with link certificates, e.g., using RootCaKeyUpdateContent ([Section 5.3.19.15](#)).

```
OOBCert ::= Certificate
```

The fields within this certificate are restricted as follows:

- The certificate **MUST** be self-signed (i.e., the signature must be verifiable using the SubjectPublicKeyInfo field);
- The subject and issuer fields **MUST** be identical;
- If the subject field contains a "NULL-DN", then both subjectAltNames and issuerAltNames extensions **MUST** be present and have exactly the same value; and
- The values of all other extensions must be suitable for a self-signed certificate (e.g., key identifiers for the subject and issuer must be the same).

```
OOBCertHash ::= SEQUENCE {  
    hashAlg      [0] AlgorithmIdentifier    OPTIONAL,  
    certId       [1] CertId                 OPTIONAL,  
    hashVal      BIT STRING  
}
```

The intention of the hash value is that anyone who has securely received the hash value (via the out-of-band means) can verify a self-signed certificate for that CA.

5.2.6. Archive Options

Requesters may indicate that they wish the PKI to archive a private key value using the PKIArchiveOptions structure.

See [\[RFC4211\]](#) for PKIArchiveOptions syntax.

5.2.7. Publication Information

Requesters may indicate that they wish the PKI to publish a certificate using the PKIPublicationInfo structure.

See [\[RFC4211\]](#) for PKIPublicationInfo syntax.

5.2.8. POP Structures

The POP structure used is indicated in the popo field of type ProofOfPossession in the CertReqMsg sequence (see [Section 4](#) of [\[RFC4211\]](#)).

```
ProofOfPossession ::= CHOICE {  
    raVerified      [0] NULL,  
    signature       [1] POPOSigningKey,  
    keyEncipherment [2] POPOPrivKey,  
    keyAgreement    [3] POPOPrivKey  
}
```

5.2.8.1. raVerified

An EE **MUST NOT** use raVerified. If an RA performs changes to a certification request breaking the provided POP, or if the RA requests a certificate on behalf of an EE and cannot provide the POP itself, the RA **MUST** use raVerified. Otherwise, it **SHOULD NOT** use raVerified.

When introducing raVerified, the RA **MUST** check the existing POP, or it **MUST** ensure by other means that the EE is the holder of the private key. The RA **MAY** provide the original message containing the POP in the generalInfo field using the id-it-origPKIMessage (see [Section 5.1.1.3](#)) enabling the CA to verify it.

5.2.8.2. POPOSigningKey Structure

If the certification request is for a key pair that supports signing (i.e., a request for a verification certificate), then the POP of the private key is demonstrated through use of the POPOSigningKey structure; for details, see [Section 4.1](#) of [\[RFC4211\]](#).

```
POPOSigningKey ::= SEQUENCE {  
    poposkInput [0] POPOSigningKeyInput OPTIONAL,  
    algorithmIdentifier AlgorithmIdentifier,  
    signature BIT STRING  
}  
  
POPOSigningKeyInput ::= SEQUENCE {  
    authInfo CHOICE {  
        sender [0] GeneralName,  
        publicKeyMAC PKMACValue  
    },  
    publicKey SubjectPublicKeyInfo  
}  
  
PKMACValue ::= SEQUENCE {  
    algId AlgorithmIdentifier,  
    value BIT STRING  
}
```

Note: For the purposes of this specification, the ASN.1 comment given in [Appendix C](#) of [\[RFC4211\]](#) pertains not only to certTemplate but also to the altCertTemplate control, as defined in [Section 5.2.1](#).

If certTemplate (or the altCertTemplate control) contains the subject and publicKey values, then poposkInput **MUST** be omitted and the signature **MUST** be computed on the DER-encoded value of the certReq field of the CertReqMsg (or the DER-encoded value of AltCertTemplate). If

certTemplate/altCertTemplate does not contain both the subject and public key values (i.e., if it contains only one of these or neither), then poposkInput **MUST** be present and the signature **MUST** be computed on the DER-encoded value of poposkInput (i.e., the "value" OCTETs of the POPOSigningKeyInput DER).

In the special case that the CA/RA has a DH certificate that is known to the EE and the certification request is for a key agreement key pair, the EE can also use the POPOSigningKey structure (where the algorithmIdentifier field is DHBasedMAC and the signature field is the MAC) for demonstrating POP.

5.2.8.3. POPOPrivKey Structure

If the certification request is for a key pair that does not support signing (i.e., a request for an encryption or key agreement certificate), then the POP of the private key is demonstrated through use of the POPOPrivKey structure in one of the following three ways; for details see Sections 4.2 and 4.3 in [RFC4211].

```
POPOPrivKey ::= CHOICE {
    thisMessage [0] BIT STRING, -- deprecated
    subsequentMessage [1] SubsequentMessage,
    dhMAC [2] BIT STRING, -- deprecated
    agreeMAC [3] PKMACValue,
    encryptedKey [4] EnvelopedData
}

SubsequentMessage ::= INTEGER {
    encrCert (0),
    challengeResp (1)
}
```

When using agreeMAC or encryptedKey choices, the pvno cmp2021(3) **MUST** be used. Details on the usage of the pvno are described in Section 7.

5.2.8.3.1. Inclusion of the Private Key

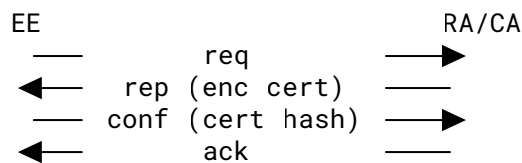
This method mentioned previously in Section 4.3 demonstrates POP of the private key by including the encrypted private key in the CertRequest in the POPOPrivKey structure or in the PKIArchiveOptions control structure. This method **SHALL** only be used if archival of the private key is desired.

For a certification request message indicating cmp2021(3) in the pvno field of the PKIHeader, the encrypted private key **MUST** be transferred in the encryptedKey choice of POPOPrivKey (or within the PKIArchiveOptions control) in a CMS EnvelopedData structure, as defined in Section 5.2.2.

Note: The `thisMessage` choice has been deprecated in favor of `encryptedKey`. When using `cmp2000(2)` in the certification request message header for backward compatibility, the `thisMessage` choice of `POPOPrivKey` is used containing the encrypted private key in an `EncryptedValue` structure wrapped in a `BIT STRING`. This allows the necessary conveyance and protection of the private key while maintaining bits-on-the-wire compatibility with [RFC4211].

5.2.8.3.2. Indirect Method - Encrypted Certificate

The indirect method mentioned previously in [Section 4.3](#) demonstrates POP of the private key by having the CA return the requested certificate in encrypted form (see [Section 5.2.2](#)). This method is indicated in the `CertRequest` by requesting the `encrCert` option in the `subsequentMessage` choice of `POPOPrivKey`.



The EE proves knowledge of the private key to the CA by providing the correct `CertHash` for this certificate in the `certConf` message. This demonstrates POP because the EE can only compute the correct `CertHash` if it is able to recover the encrypted certificate, and it can only recover the certificate if it is able to obtain the symmetric key using the required private key. Clearly, for this to work, the CA **MUST NOT** publish the certificate until the `certConf` message arrives (when `certHash` is to be used to demonstrate POP). See [Section 5.3.18](#) for further details, and see [Section 8.11](#) for security considerations regarding use of CT logs.

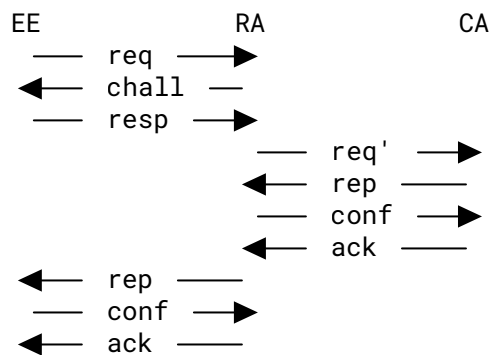
The recipient **SHOULD** maintain a context of the PKI management operation, e.g., using `transactionID` and `certReqId`, to identify the private key to use when decrypting the `EnvelopedData` containing the newly issued certificate. The recipient may be unable to use the `RecipientInfo` structure as it refers to the certificate that is still encrypted. The sender **MUST** populate the `rid` field as specified by CMS, and the client **MAY** ignore it.

5.2.8.3.3. Direct Method - Challenge-Response Protocol

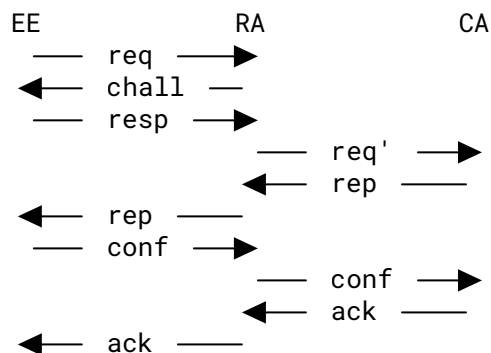
The direct method mentioned previously in [Section 4.3](#) demonstrates POP of the private key by having the EE engage in a challenge-response protocol (using the messages `popdecc` of type `POPODecKeyChall` and `popdecr` of type `POPODecKeyResp`; see below) between `CertReqMessages` and `CertRepMessage`. This method is indicated in the `CertRequest` by requesting the `challengeResp` option in the `subsequentMessage` choice of `POPOPrivKey`.

Note: This method would typically be used in an environment in which an RA verifies POP and then makes a certification request to the CA on behalf of the EE. In such a scenario, the CA trusts the RA to have done POP correctly before the RA requests a certificate for the EE.

The complete protocol then looks as follows (note that req' does not necessarily encapsulate req as a nested message):



This protocol is obviously much longer than the exchange given in [Section 5.2.8.3.2](#) above but allows a Local Registration Authority (LRA) to be involved and has the property that the certificate itself is not actually created until the POP is complete. In some environments, a different order of the above messages may be required, such as the following (this may be determined by policy):



The challenge-response messages for POP of a private key are specified as follows (for decryption keys, see [\[MvOV97\]](#), p.404 for details). This challenge-response exchange is associated with the preceding certification request message (and subsequent certification response and confirmation messages) by the transactionID used in the PKIHeader and by the protection applied to the PKIMessage.

```
POPODecKeyChallContent ::= SEQUENCE OF Challenge

Challenge ::= SEQUENCE {
    owf AlgorithmIdentifier OPTIONAL,
    witness OCTET STRING,
    challenge OCTET STRING, -- deprecated
    encryptedRand [0] EnvelopedData OPTIONAL
}

Rand ::= SEQUENCE {
    int INTEGER,
    sender GeneralName
}
```

More details on the fields in this syntax are available in [Appendix F](#).

For a popdecc message indicating cmp2021(3) in the pvno field of the PKIHeader, the encryption of Rand **MUST** be transferred in the encryptedRand field in a CMS EnvelopedData structure as defined in [Section 5.2.2](#). The challenge field **MUST** contain an empty OCTET STRING.

The recipient **SHOULD** maintain a context of the PKI management operation, e.g., using transactionID and certReqId, to identify the private key to use when decrypting encryptedRand. The sender **MUST** populate the rid field in the EnvelopedData sequence using the issuerAndSerialNumber choice containing a NULL-DN as issuer and the certReqId as serialNumber. The client **MAY** ignore the rid field.

Note: The challenge field has been deprecated in favor of encryptedRand. When using cmp2000(2) in the popdecc message header for backward compatibility, the challenge field **MUST** contain the encryption (involving the public key for which the certification request is being made) of Rand and encryptedRand **MUST** be omitted. Using challenge (omitting the optional encryptedRand field) is bit-compatible with [\[RFC4210\]](#). Note that the size of Rand, when used with challenge, needs to be appropriate for encryption, involving the public key of the requester. If, in some environment, names are so long that they cannot fit (e.g., very long DN's), then whatever portion will fit should be used (as long as it includes at least the common name, and as long as the receiver is able to deal meaningfully with the abbreviation).

```
POPODecKeyRespContent ::= SEQUENCE OF INTEGER
```

On receiving the popdecc message, the EE decrypts all included challenges and responds with a popdecr message containing the decrypted integer values in the same order.

5.2.8.4. Summary of POP Options

The text in this section provides several options with respect to POP techniques. Using "SK" for "signing key", "EK" for "encryption key", "KAK" for "key agreement key", and "KEMK" for "key encapsulation mechanism key", the techniques may be summarized as follows:

RAVerified;

SKPOP;
EKPOPThisMessage; -- deprecated
KAKPOPThisMessage; -- deprecated
EKPOPEncryptedKey;
KAKPOPEncryptedKey;
KEMKPOPEncryptedKey;
KAKPOPThisMessageDHMAC;
EKPOPEncryptedCert;
KAKPOPEncryptedCert;
KEMKPOPEncryptedCert;
EKPOPChallengeResp;
KAKPOPChallengeResp; and
KEMKPOPChallengeResp.

Given this array of options, it is natural to ask how an EE can know what is supported by the CA/RA (i.e., which options it may use when requesting certificates). The following guidelines should clarify this situation for EE implementers.

- **RAVerified:** This is not an EE decision; the RA uses this if and only if it has verified POP before forwarding the request on to the CA, so it is not possible for the EE to choose this technique.
- **SKPOP:** If the EE has a signing key pair, this is the only POP method specified for use in the request for a corresponding certificate.
- **EKPOPThisMessage (deprecated), KAKPOPThisMessage (deprecated), EKPOPEncryptedKey, KAKPOPEncryptedKey, KEMKPOPEncryptedKey:** Whether or not to give up its private key to the CA/RA is an EE decision. If the EE decides to reveal its key, then these are the only POP methods available in this specification to achieve this (and the key pair type and protocol version used will determine which of these methods to use). The reason for deprecating EKPOPThisMessage and KAKPOPThisMessage options has been given in [Section 5.2.8.3.1](#).
- **KAKPOPThisMessageDHMAC:** The EE can only use this method if (1) the CA/RA has a DH certificate available for this purpose and (2) the EE already has a copy of this certificate. If both these conditions hold, then this technique is clearly supported and may be used by the EE, if desired.
- **EKPOPEncryptedCert, KAKPOPEncryptedCert, KEMKPOPEncryptedCert, EKPOPChallengeResp, KAKPOPChallengeResp, and KEMKPOPChallengeResp:** The EE picks one of these (in the subsequentMessage field) in the request message, depending upon preference and key pair type. The EE is not doing POP at this point; it is simply indicating which method it wants to use. Therefore, if the CA/RA replies with a "badPOP" error, the EE can re-request using the other POP method chosen in subsequentMessage. Note, however, that this specification encourages the use of the EncryptedCert choice and, furthermore, says that the challenge-response would typically be used when an RA is involved and doing

POP verification. Thus, the EE should be able to make an intelligent decision regarding which of these POP methods to choose in the request message.

5.2.9. GeneralizedTime

GeneralizedTime is a standard ASN.1 type and **SHALL** be used as specified in [Section 4.1.2.5.2](#) of [\[RFC5280\]](#).

5.3. Operation-Specific Data Structures

5.3.1. Initialization Request

An Initialization request message contains as the PKIBody a CertReqMessages data structure, which specifies the requested certificate(s). Typically, SubjectPublicKeyInfo, KeyId, and Validity are the template fields that may be supplied for each certificate requested (see the profiles defined in [Section 4.1.1](#) of [\[RFC9483\]](#) and Appendices [C.4](#) and [D.7](#) for further information). This message is intended to be used for entities when first initializing into the PKI.

See [Section 5.2.1](#) and [\[RFC4211\]](#) for CertReqMessages syntax.

5.3.2. Initialization Response

An Initialization response message contains as the PKIBody a CertRepMessage data structure, which has for each certificate requested a PKIStatusInfo field, a subject certificate, and possibly a private key (normally encrypted using EnvelopedData; see [Section 4.1.6](#) of [\[RFC9483\]](#) for further information).

See [Section 5.3.4](#) for CertRepMessage syntax. Note that if the PKI message protection is "shared secret information" (see [Section 5.1.3.1](#)), then any certificate transported in the caPubs field may be directly trusted as a root CA certificate by the initiator.

5.3.3. Certification Request

A Certification request message contains as the PKIBody a CertReqMessages data structure, which specifies the requested certificates (see the profiles defined in [Section 4.1.2](#) of [\[RFC9483\]](#) and [Appendix C.2](#) for further information). This message is intended to be used for existing PKI entities who wish to obtain additional certificates.

See [Section 5.2.1](#) and [\[RFC4211\]](#) for CertReqMessages syntax.

Alternatively, the PKIBody **MAY** be a CertificationRequest (this structure is fully specified by the ASN.1 structure CertificationRequest given in [\[RFC2986\]](#); see the profiles defined in [Section 4.1.4](#) of [\[RFC9483\]](#) for further information). This structure may be required for certificate requests for signing key pairs when interoperation with legacy systems is desired, but its use is strongly discouraged whenever not absolutely necessary.

5.3.4. Certification Response

A Certification response message contains as the PKIBody a CertRepMessage data structure, which has a status value for each certificate requested and optionally has a CA public key, failure information, a subject certificate, and an encrypted private key.

```
CertRepMessage ::= SEQUENCE {
    caPubs          [1] SEQUENCE SIZE (1..MAX) OF CMPCertificate
                    OPTIONAL,
    response        SEQUENCE OF CertResponse
}

CertResponse ::= SEQUENCE {
    certReqId       INTEGER,
    status          PKIStatusInfo,
    certifiedKeyPair CertifiedKeyPair OPTIONAL,
    rspInfo         OCTET STRING      OPTIONAL
    -- analogous to the id-regInfo-utf8Pairs string defined
    -- for regInfo in CertReqMsg [RFC4211]
}

CertifiedKeyPair ::= SEQUENCE {
    certOrEncCert   CertOrEncCert,
    privateKey      [0] EncryptedKey OPTIONAL,
    -- See [RFC4211] for comments on encoding.
    publicationInfo [1] PKIPublicationInfo OPTIONAL
}

CertOrEncCert ::= CHOICE {
    certificate      [0] CMPCertificate,
    encryptedCert   [1] EncryptedKey
}
```

A p10cr message contains exactly one CertificationRequestInfo data structure, as specified in PKCS #10 [RFC2986], but no certReqId. Therefore, the certReqId in the corresponding Certification Response (cp) message **MUST** be set to -1.

Only one of the failInfo (in PKIStatusInfo) and certificate (in CertifiedKeyPair) fields can be present in each CertResponse (depending on the status). For some status values (e.g., waiting), neither of the optional fields will be present.

Given an EncryptedCert and the relevant decryption key, the certificate may be obtained. The purpose of this is to allow a CA to return the value of a certificate but with the constraint that only the intended recipient can obtain the actual certificate. The benefit of this approach is that a CA may reply with a certificate even in the absence of proof that the requester is the EE that can use the relevant private key (note that the proof is not obtained until the certConf message is received by the CA). Thus, the CA will not have to revoke that certificate in the event that something goes wrong with the POP (but **MAY** do so anyway, depending upon policy).

The use of EncryptedKey is described in [Section 5.2.2](#).

Note: To indicate support for EnvelopedData, the pvno cmp2021 has been introduced. Details on the usage of different protocol version numbers are described in [Section 7](#).

5.3.5. Key Update Request Content

For key update requests, the CertReqMessages syntax is used. Typically, SubjectPublicKeyInfo, KeyId, and Validity are the template fields that may be supplied for each key to be updated (see the profiles defined in [Section 4.1.3](#) of [RFC9483] and [Appendix C.6](#) for further information). This message is intended to be used to request updates to existing (non-revoked and non-expired) certificates (therefore, it is sometimes referred to as a "Certificate Update" operation). An update is a replacement certificate containing either a new subject public key or the current subject public key (although the latter practice may not be appropriate for some environments).

See [Section 5.2.1](#) and [RFC4211] for CertReqMessages syntax.

5.3.6. Key Update Response Content

For key update responses, the CertRepMessage syntax is used. The response is identical to the initialization response.

See [Section 5.3.4](#) for CertRepMessage syntax.

5.3.7. Key Recovery Request Content

For key recovery requests, the syntax used is identical to the initialization request CertReqMessages. Typically, SubjectPublicKeyInfo and KeyId are the template fields that may be used to supply a signature public key for which a certificate is required.

See [Section 5.2.1](#) and [RFC4211] for CertReqMessages syntax. Note that if a key history is required, the requester must supply a protocol encryption key control in the request message.

5.3.8. Key Recovery Response Content

For key recovery responses, the following syntax is used. For some status values (e.g., waiting), none of the optional fields will be present.

```
KeyRecRepContent ::= SEQUENCE {
    status          PKIStatusInfo,
    newSigCert      [0] Certificate OPTIONAL,
    caCerts         [1] SEQUENCE SIZE (1..MAX) OF
                     Certificate OPTIONAL,
    keyPairHist     [2] SEQUENCE SIZE (1..MAX) OF
                     CertifiedKeyPair OPTIONAL
}
```

5.3.9. Revocation Request Content

When requesting revocation of a certificate (or several certificates), the following data structure is used (see the profiles defined in [Section 4.2](#) of [RFC9483] for further information). The name of the requester is present in the PKIHeader structure.

```
RevReqContent ::= SEQUENCE OF RevDetails

RevDetails ::= SEQUENCE {
    certDetails      CertTemplate,
    crlEntryDetails  Extensions      OPTIONAL
}
```

5.3.10. Revocation Response Content

The revocation response is the response to the above message. If produced, this is sent to the requester of the revocation. (A separate revocation announcement message **MAY** be sent to the subject of the certificate for which revocation was requested.)

```
RevRepContent ::= SEQUENCE {
    status      SEQUENCE SIZE (1..MAX) OF PKIStatusInfo,
    revCerts    [0] SEQUENCE SIZE (1..MAX) OF CertId OPTIONAL,
    crls        [1] SEQUENCE SIZE (1..MAX) OF CertificateList
                OPTIONAL
}
```

5.3.11. Cross-Certification Request Content

Cross-certification requests use the same syntax (CertReqMessages) as normal certification requests, with the restriction that the key pair **MUST** have been generated by the requesting CA and the private key **MUST NOT** be sent to the responding CA (see the profiles defined in [Appendix D.6](#) for further information). This request **MAY** also be used by subordinate CAs to get their certificates signed by the parent CA.

See [Section 5.2.1](#) and [\[RFC4211\]](#) for CertReqMessages syntax.

5.3.12. Cross-Certification Response Content

Cross-certification responses use the same syntax (CertRepMessage) as normal certification responses, with the restriction that no encrypted private key can be sent.

See [Section 5.3.4](#) for CertRepMessage syntax.

5.3.13. CA Key Update Announcement Content

When a CA updates its own key pair, the following data structure **MAY** be used to announce this event.

```
RootCaKeyUpdateContent ::= SEQUENCE {
    newWithNew          CMPCertificate,
    newWithOld          [0] CMPCertificate OPTIONAL,
    oldWithNew          [1] CMPCertificate OPTIONAL
}

CAKeyUpdContent ::= CHOICE {
    cAKeyUpdAnnV2      CAKeyUpdAnnContent, -- deprecated
    cAKeyUpdAnnV3      [0] RootCaKeyUpdateContent
}
```

When using `RootCaKeyUpdateContent` in the `ckuann` message, the `pvno cmp2021` **MUST** be used. Details on the usage of the `pvno` are described in [Section 7](#).

In contrast to `CAKeyUpdAnnContent` as supported with `cmp2000`, `RootCaKeyUpdateContent` offers omitting `newWithOld` and `oldWithNew`, depending on the needs of the EE.

5.3.14. Certificate Announcement

This structure **MAY** be used to announce the existence of certificates.

Note that this message is intended to be used for those cases (if any) where there is no pre-existing method for publication of certificates; it is not intended to be used where, for example, X.500 is the method for publication of certificates.

```
CertAnnContent ::= Certificate
```

5.3.15. Revocation Announcement

When a CA has revoked, or is about to revoke, a particular certificate, it **MAY** issue an announcement of this (possibly upcoming) event.

```
RevAnnContent ::= SEQUENCE {
    status          PKIStatus,
    certId          CertId,
    willBeRevokedAt GeneralizedTime,
    badSinceDate    GeneralizedTime,
    crlDetails      Extensions OPTIONAL
}
```

A CA **MAY** use such an announcement to warn (or notify) a subject that its certificate is about to be (or has been) revoked. This would typically be used where the request for revocation did not come from the subject concerned.

The `willBeRevokedAt` field contains the time at which a new entry will be added to the relevant CRLs.

5.3.16. CRL Announcement

When a CA issues a new CRL (or set of CRLs), the following data structure **MAY** be used to announce this event.

```
CRLAnnContent ::= SEQUENCE OF CertificateList
```

5.3.17. PKI Confirmation Content

This data structure is used in the protocol exchange as the final PKIMessage. Its content is the same in all cases -- actually, there is no content since the PKIHeader carries all the required information.

```
PKIConfirmContent ::= NULL
```

Use of this message for certificate confirmation is **NOT RECOMMENDED**; certConf **SHOULD** be used instead. Upon receiving a pkiconf for a certificate response, the recipient **MAY** treat it as a certConf with all certificates being accepted.

5.3.18. Certificate Confirmation Content

This data structure is used by the client to send a confirmation to the CA/RA to accept or reject certificates.

```
CertConfirmContent ::= SEQUENCE OF CertStatus

CertStatus ::= SEQUENCE {
    certHash      OCTET STRING,
    certReqId     INTEGER,
    statusInfo    PKIStatusInfo OPTIONAL,
    hashAlg [0]   AlgorithmIdentifier{DIGEST-ALGORITHM, {...}}
                  OPTIONAL
}
```

The hashAlg field **SHOULD** be used only in exceptional cases where the signatureAlgorithm of the certificate to be confirmed does not specify a hash algorithm in the OID or in the parameters or no hash algorithm is specified for hashing certificates signed using the signatureAlgorithm. Note that for EdDSA, a hash algorithm is specified in [Section 3.3](#) of [\[RFC9481\]](#), such that the hashAlg field is not needed for EdDSA. Otherwise, the certHash value **SHALL** be computed using the same hash algorithm as used to create and verify the certificate signature or as specified for hashing certificates signed using the signatureAlgorithm. If hashAlg is used, the CMP version indicated by the certConf message header must be cmp2021(3).

For any particular CertStatus, omission of the statusInfo field indicates acceptance of the specified certificate. Alternatively, explicit status details (with respect to acceptance or rejection) **MAY** be provided in the statusInfo field, perhaps for auditing purposes at the CA/RA.

Within CertConfirmContent, omission of a CertStatus structure corresponding to a certificate supplied in the previous response message indicates rejection of the certificate. Thus, an empty CertConfirmContent (a zero-length SEQUENCE) **MAY** be used to indicate rejection of all supplied certificates. See [Section 5.2.8.3.2](#) for a discussion of the certHash field with respect to POP.

5.3.19. PKI General Message Content

```

InfoTypeAndValue ::= SEQUENCE {
    infoType          OBJECT IDENTIFIER,
    infoValue         ANY DEFINED BY infoType OPTIONAL
}

-- where {id-it} = {id-pkix 4} = {1 3 6 1 5 5 7 4}
GenMsgContent ::= SEQUENCE OF InfoTypeAndValue

```

5.3.19.1. CA Protocol Encryption Certificate

This **MAY** be used by the EE to get a certificate from the CA to use to protect sensitive information during the protocol.

```

GenMsg:    {id-it 1}, < absent >
GenRep:    {id-it 1}, Certificate | < absent >

```

EEs **MUST** ensure that the correct certificate is used for this purpose.

5.3.19.2. Signing Key Pair Types

This **MAY** be used by the EE to get the list of signature algorithms whose subject public key values the CA is willing to certify.

```

GenMsg:    {id-it 2}, < absent >
GenRep:    {id-it 2}, SEQUENCE SIZE (1..MAX) OF
                AlgorithmIdentifier

```

Note: For the purposes of this exchange, rsaEncryption and sha256WithRSAEncryption, for example, are considered to be equivalent; the question being asked is, "Is the CA willing to certify an RSA public key?"

Note: In case several elliptic curves are supported, several id-ecPublicKey elements as defined in [\[RFC5480\]](#) need to be given, one per named curve.

5.3.19.3. Encryption / Key Agreement Key Pair Types

This **MAY** be used by the client to get the list of encryption / key agreement algorithms whose subject public key values the CA is willing to certify.


```
GenMsg:    {id-it 3}, < absent >
GenRep:    {id-it 3}, SEQUENCE SIZE (1..MAX) OF
              AlgorithmIdentifier
```

Note: In case several elliptic curves are supported, several id-ecPublicKey elements as defined in [\[RFC5480\]](#) need to be given, one per named curve.

5.3.19.4. Preferred Symmetric Algorithm

This **MAY** be used by the client to get the CA-preferred symmetric encryption algorithm for any confidential information that needs to be exchanged between the EE and the CA (for example, if the EE wants to send its private decryption key to the CA for archival purposes).

```
GenMsg:    {id-it 4}, < absent >
GenRep:    {id-it 4}, AlgorithmIdentifier
```

5.3.19.5. Updated CA Key Pair

This **MAY** be used by the CA to announce a CA key update event.

```
GenMsg:    {id-it 18}, RootCaKeyUpdateValue
```

See [Section 5.3.13](#) for details of CA key update announcements.

5.3.19.6. CRL

This **MAY** be used by the client to get a copy of the latest CRL.

```
GenMsg:    {id-it 6}, < absent >
GenRep:    {id-it 6}, CertificateList
```

5.3.19.7. Unsupported Object Identifiers

This is used by the server to return a list of object identifiers that it does not recognize or support from the list submitted by the client.

```
GenRep:    {id-it 7}, SEQUENCE SIZE (1..MAX) OF OBJECT IDENTIFIER
```

5.3.19.8. Key Pair Parameters

This **MAY** be used by the EE to request the domain parameters to use for generating the key pair for certain public-key algorithms. It can be used, for example, to request the appropriate P, Q, and G to generate the DH/DSA key or to request a set of well-known elliptic curves.

```
GenMsg:    {id-it 10}, OBJECT IDENTIFIER -- (Algorithm object-id)
GenRep:    {id-it 11}, AlgorithmIdentifier | < absent >
```

An absent infoValue in the GenRep indicates that the algorithm specified in GenMsg is not supported.

EEs **MUST** ensure that the parameters are acceptable to it and that the GenRep message is authenticated (to avoid substitution attacks).

5.3.19.9. Revocation Passphrase

This **MAY** be used by the EE to send a passphrase to a CA/RA for the purpose of authenticating a later revocation request (in the case that the appropriate signing private key is no longer available to authenticate the request). See [Appendix B](#) for further details on the use of this mechanism.

```
GenMsg:    {id-it 12}, EncryptedKey
GenRep:    {id-it 12}, < absent >
```

The use of EncryptedKey is described in [Section 5.2.2](#).

5.3.19.10. ImplicitConfirm

See [Section 5.1.1.1](#) for the definition and use of {id-it 13}.

5.3.19.11. ConfirmWaitTime

See [Section 5.1.1.2](#) for the definition and use of {id-it 14}.

5.3.19.12. Original PKIMessage

See [Section 5.1.1.3](#) for the definition and use of {id-it 15}.

5.3.19.13. Supported Language Tags

This **MAY** be used to determine the appropriate language tag [[RFC5646](#)] to use in subsequent messages. The sender sends its list of supported languages (in order of most to least preferred); the receiver returns the one it wishes to use. (Note: Each UTF8String **MUST** include a language tag.) If none of the offered tags are supported, an error **MUST** be returned.

```
GenMsg:    {id-it 16}, SEQUENCE SIZE (1..MAX) OF UTF8String
GenRep:    {id-it 16}, SEQUENCE SIZE (1) OF UTF8String
```

5.3.19.14. CA Certificates

This **MAY** be used by the client to get CA certificates.

```

GenMsg:    {id-it 17}, < absent >
GenRep:    {id-it 17}, SEQUENCE SIZE (1..MAX) OF
              CMPCertificate | < absent >

```

5.3.19.15. Root CA Update

This **MAY** be used by the client to get an update of a root CA certificate, which is provided in the body of the request message. In contrast to the ckuann message, this approach follows the request/response model.

The EE **SHOULD** reference its current trust anchor in RootCaCertValue in the request body, giving the root CA certificate if available.

```

GenMsg:    {id-it 20}, RootCaCertValue | < absent >
GenRep:    {id-it 18}, RootCaKeyUpdateValue | < absent >

```

```

RootCaCertValue ::= CMPCertificate

RootCaKeyUpdateValue ::= RootCaKeyUpdateContent

RootCaKeyUpdateContent ::= SEQUENCE {
    newWithNew          CMPCertificate,
    newWithOld          [0] CMPCertificate OPTIONAL,
    oldWithNew          [1] CMPCertificate OPTIONAL
}

```

Note: In contrast to CAKeyUpdAnnContent (which was deprecated with pvno cmp2021), RootCaKeyUpdateContent offers omitting newWithOld and oldWithNew, depending on the needs of the EE.

5.3.19.16. Certificate Request Template

This **MAY** be used by the client to get a template containing requirements for certificate request attributes and extensions. The controls id-regCtrl-algId and id-regCtrl-rsaKeyLen **MAY** contain details on the types of subject public keys the CA is willing to certify.

The id-regCtrl-algId control **MAY** be used to identify a cryptographic algorithm (see [Section 4.1.2.7](#) of [\[RFC5280\]](#)) other than rsaEncryption. The algorithm field **SHALL** identify a cryptographic algorithm. The contents of the optional parameters field will vary according to the algorithm identified. For example, when the algorithm is set to id-ecPublicKey, the parameters identify the elliptic curve to be used; see [\[RFC5480\]](#).

Note: The client may specify a profile name in the certProfile field (see [Section 5.1.1.4](#)).

The id-regCtrl-rsaKeyLen control **SHALL** be used for algorithm rsaEncryption and **SHALL** contain the intended modulus bit length of the RSA key.

```

GenMsg:    {id-it 19}, < absent >
GenRep:    {id-it 19}, CertReqTemplateContent | < absent >

```

```

CertReqTemplateValue ::= CertReqTemplateContent

CertReqTemplateContent ::= SEQUENCE {
    certTemplate      CertTemplate,
    keySpec           Controls OPTIONAL }

Controls ::= SEQUENCE SIZE (1..MAX) OF AttributeTypeAndValue

id-regCtrl-algId OBJECT IDENTIFIER ::= { iso(1)
    identified-organization(3) dod(6) internet(1) security(5)
    mechanisms(5) pkix(7) pkix(5) regCtrl(1) 11 }

AlgIdCtrl ::= AlgorithmIdentifier{ALGORITHM, {...}}

id-regCtrl-rsaKeyLen OBJECT IDENTIFIER ::= { iso(1)
    identified-organization(3) dod(6) internet(1) security(5)
    mechanisms(5) pkix(7) pkix(5) regCtrl(1) 12 }

RsaKeyLenCtrl ::= INTEGER (1..MAX)

```

The `CertReqTemplateValue` contains the prefilled `certTemplate` to be used for a future certificate request. The `publicKey` field in the `certTemplate` **MUST NOT** be used. In case the PKI management entity wishes to specify supported public-key algorithms, the `keySpec` field **MUST** be used. One `AttributeTypeAndValue` per supported algorithm or RSA key length **MUST** be used.

Note: The controls for an ASN.1 type are defined in [Section 6](#) of CRMF [\[RFC4211\]](#).

5.3.19.17. CRL Update Retrieval

This **MAY** be used by the client to get new CRLs, specifying the source of the CRLs and the `thisUpdate` value of the latest CRL it already has, if available. A CRL source is given either by a `DistributionPointName` or the `GeneralNames` of the issuing CA. The `DistributionPointName` should be treated as an internal pointer to identify a CRL that the server already has and not as a way to ask the server to fetch CRLs from external locations. The server **SHALL** only provide those CRLs that are more recent than the ones indicated by the client.

```

GenMsg:    {id-it 22}, SEQUENCE SIZE (1..MAX) OF CRLStatus
GenRep:    {id-it 23}, SEQUENCE SIZE (1..MAX) OF
              CertificateList | < absent >

```

```
CRLSource ::= CHOICE {  
    dpn          [0] DistributionPointName,  
    issuer       [1] GeneralNames }  
  
CRLStatus ::= SEQUENCE {  
    source      CRLSource,  
    thisUpdate  Time OPTIONAL }
```

5.3.19.18. KEM Ciphertext

This **MAY** be used by a PKI entity to get the KEM ciphertext for MAC-based message protection using KEM (see [Section 5.1.3.4](#)).

The PKI entity that possesses a KEM key pair can request the ciphertext by sending an InfoTypeAndValue structure of type KemCiphertextInfo where the infoValue is absent. The ciphertext can be provided in the following genp message with an InfoTypeAndValue structure of the same type.

```
GenMsg:    {id-it 24}, < absent >  
GenRep:    {id-it 24}, KemCiphertextInfo
```

```
KemCiphertextInfo ::= SEQUENCE {  
    kem          AlgorithmIdentifier{KEM-ALGORITHM, {...}},  
    ct           OCTET STRING  
}
```

kem is the algorithm identifier of the KEM algorithm, and any associated parameters, used to generate the ciphertext (ct).

ct is the ciphertext output from the KEM Encapsulate function.

Note: These InfoTypeAndValue structures can also be transferred in the generalInfo field of the PKIHeader in messages of other types (see [Section 5.1.1.5](#)).

5.3.20. PKI General Response Content

```
GenRepContent ::= SEQUENCE OF InfoTypeAndValue
```

Examples of GenReps that **MAY** be supported include those listed in the subsections of [Section 5.3.19](#).

5.3.21. Error Message Content

This data structure **MAY** be used by an EE, CA, or RA to convey error information and by a PKI management entity to initiate delayed delivery of responses.

```
ErrorMsgContent ::= SEQUENCE {  
    pKISStatusInfo      PKISStatusInfo,  
    errorCode           INTEGER  
    errorDetails        PKIFreeText OPTIONAL  
}
```

This message **MAY** be generated at any time during a PKI transaction. If the client sends this request, the server **MUST** respond with a pkiconf response or another error message if any part of the header is not valid.

In case a PKI management entity sends an error message to the EE with the pKISStatusInfo field containing the status "waiting", the EE **SHOULD** initiate polling as described in [Section 5.3.22](#). If the EE does not initiate polling, both sides **MUST** treat this message as the end of the transaction (if a transaction is in progress).

If protection is desired on the message, the client **MUST** protect it using the same technique (i.e., signature or MAC) as the starting message of the transaction. The CA **MUST** always sign it with a signature key.

5.3.22. Polling Request and Response

This pair of messages is intended to handle scenarios in which the client needs to poll the server to determine the status of an outstanding response (i.e., when the "waiting" PKISStatus has been received).

```
PollReqContent ::= SEQUENCE OF SEQUENCE {  
    certReqId    INTEGER }  
  
PollRepContent ::= SEQUENCE OF SEQUENCE {  
    certReqId    INTEGER,  
    checkAfter   INTEGER, -- time in seconds  
    reason       PKIFreeText OPTIONAL }
```

Unless implicit confirmation has been requested and granted, in response to an ir, cr, p10cr, kur, krr, or ccr request message, polling is initiated with an ip, cp, kup, krp, or ccp response message containing status "waiting". For any type of request message, polling can be initiated with an error response message with status "waiting". The following clauses describe how polling messages are used. It is assumed that multiple certConf messages can be sent during transactions. There will be one sent in response to each ip, cp, kup, krp, or ccp that contains a CertStatus for an issued certificate.

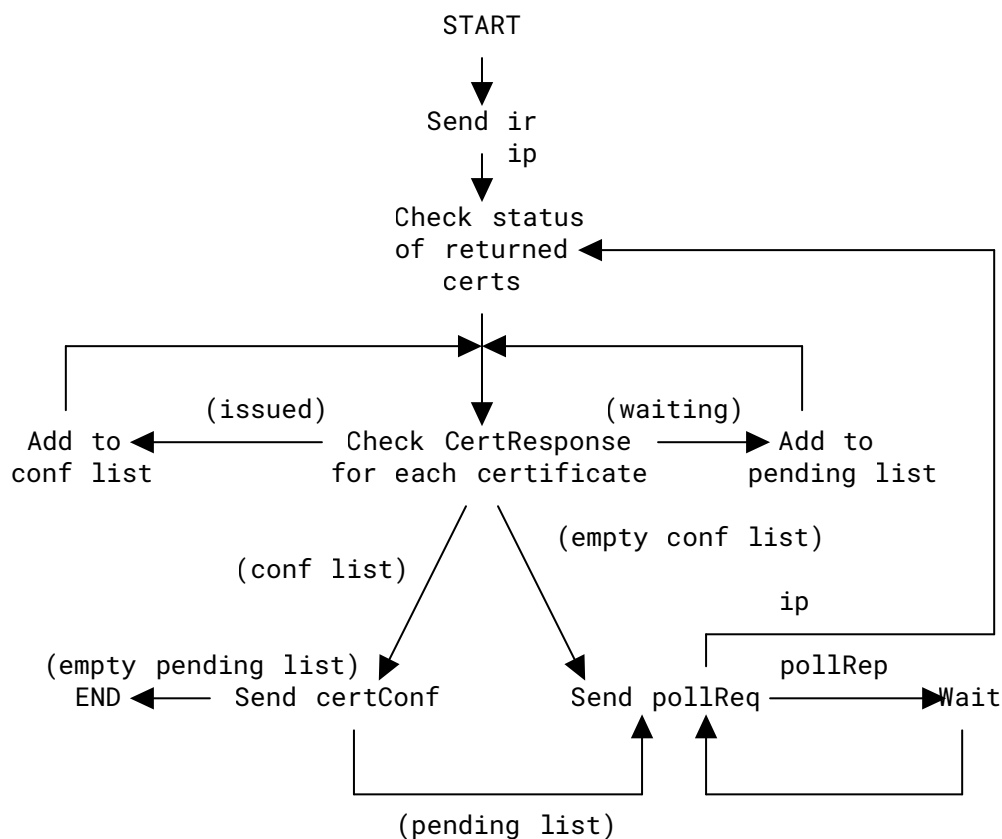
1. In response to an ip, cp, kup, krp, or ccp message, an EE will send a certConf for all issued certificates and expect a pkiconf for each certConf. An EE will send a pollReq message in response to each CertResponse element of an ip, cp, or kup message with status "waiting" and in response to an error message with status "waiting". Its certReqId **MUST** be either the index of a CertResponse data structure with status "waiting" or -1 referring to the complete response.

2. In response to a pollReq, a CA/RA will return an ip, cp, kup, krp, or ccp if one or more of the still pending requested certificates are ready or the final response to some other type of request is available; otherwise, it will return a pollRep.
3. If the EE receives a pollRep, it will wait for at least the number of seconds given in the checkAfter field before sending another pollReq.

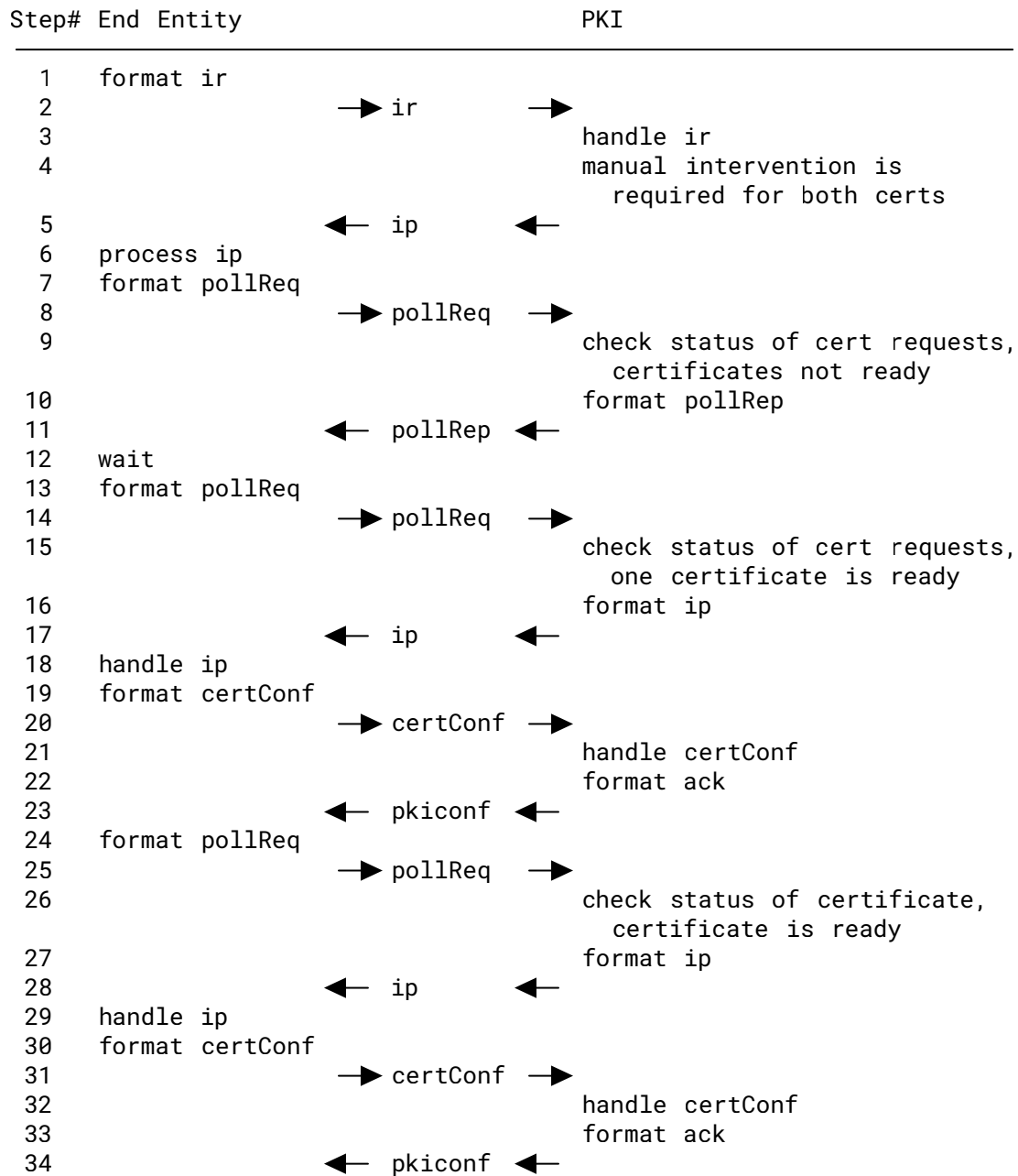
Note that the checkAfter value heavily depends on the certificate management environment. There are different possible reasons for a delayed delivery of response messages, e.g., high load on the server's backend, offline transfer of messages between two PKI management entities, or required RA operator approval. Therefore, the checkAfter time can vary greatly. This should also be considered by the transfer protocol.

4. If the EE receives an ip, cp, kup, krp, or ccp, then it will be treated in the same way as the initial response; if it receives any other response, then this will be treated as the final response to the original request.

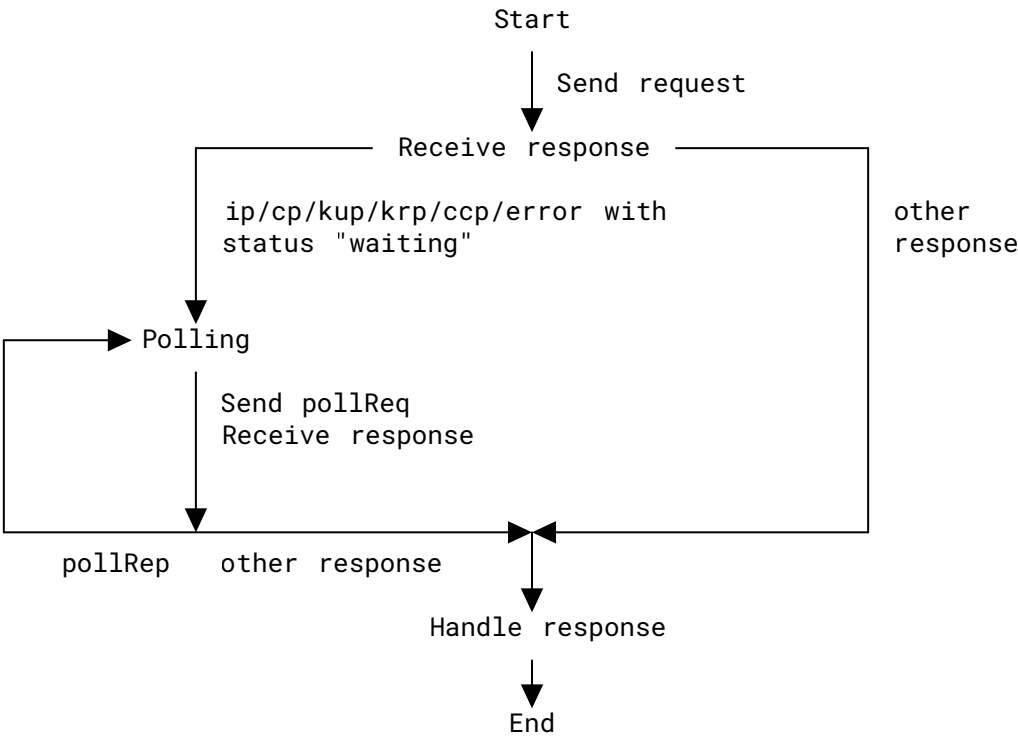
The following client-side state machine describes polling for individual CertResponse elements at the example of an ir request message.



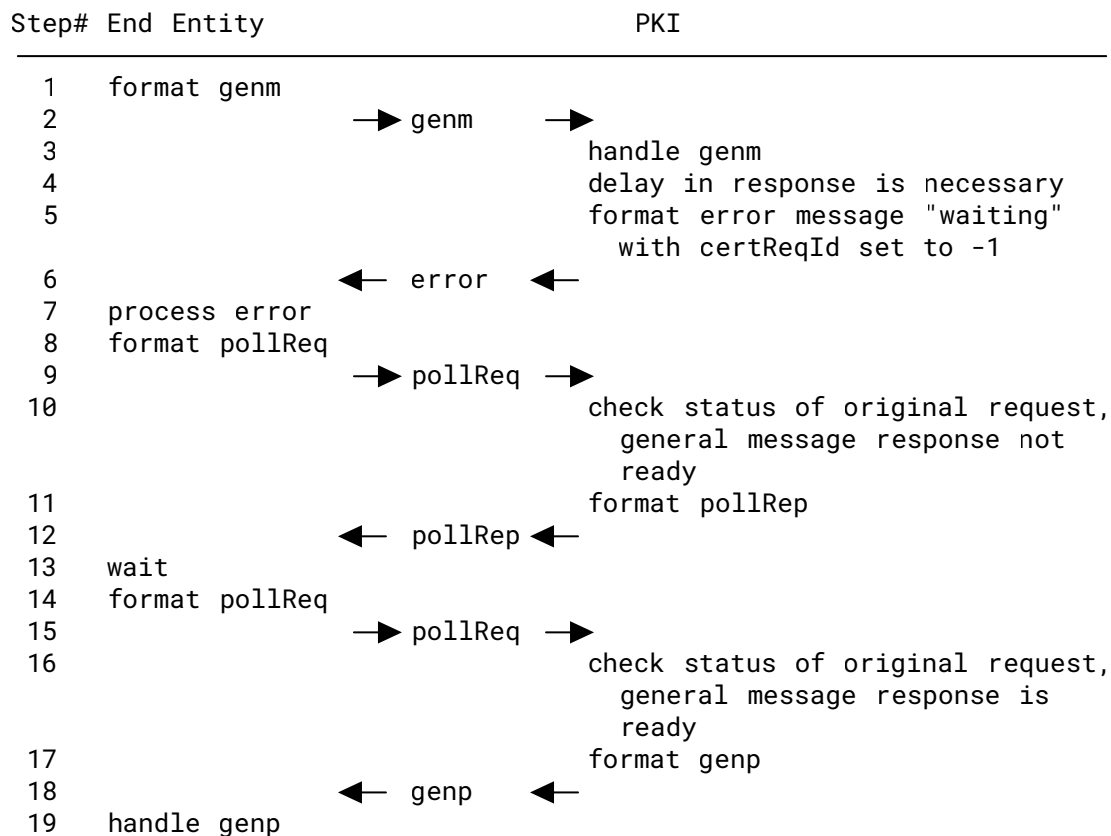
In the following exchange, the EE is enrolling for two certificates in one request.



The following client-side state machine describes polling for a complete response message.



In the following exchange, the EE is sending a general message request, and the response is delayed by the server.



6. Mandatory PKI Management Functions

Some of the PKI management functions outlined in [Section 3.1](#) are described in this section.

This section deals with functions that are "mandatory" in the sense that all EE and CA/RA implementations **MUST** be able to provide the functionality described. This part is effectively the profile of the PKI management functionality that **MUST** be supported. Note, however, that the management functions described in this section do not need to be accomplished using the PKI messages defined in [Section 5](#) if alternate means are suitable for a given environment. See [Section 7](#) of [RFC9483] and [Appendix C](#) for profiles of the PKIMessage structures that **MUST** be supported for specific use cases.

6.1. Root CA Initialization

[See [Section 3.1.1.2](#) for this document's definition of "root CA".]

If a newly created root CA is at the top of a PKI hierarchy, it usually produces a "self-certificate", which is a certificate structure with the profile defined for the "newWithNew" certificate issued following a root CA key update.

In order to make the CA's self-certificate useful to EEs that do not acquire the self-certificate via "out-of-band" means, the CA must also produce a fingerprint for its certificate. EEs that acquire this fingerprint securely via some "out-of-band" means can then verify the CA's self-certificate and, hence, the other attributes contained therein.

The data structure used to carry the fingerprint may be the OOBCertHash (see [Section 5.2.5](#)).

6.2. Root CA Key Update

CA keys (as all other keys) have a finite lifetime and will have to be updated on a periodic basis. The certificates NewWithNew, NewWithOld, and OldWithNew (see [Section 4.4.1](#)) **MAY** be issued by the CA to aid existing EEs who hold the current root CA certificate (OldWithOld) to transition securely to the new root CA certificate (NewWithNew) and to aid new EEs who will hold NewWithNew to acquire OldWithOld securely for verification of existing data.

6.3. Subordinate CA Initialization

[See [Section 3.1.1.2](#) for this document's definition of "subordinate CA".]

From the perspective of PKI management protocols, the initialization of a subordinate CA is the same as the initialization of an EE. The only difference is that the subordinate CA must also produce an initial revocation list.

6.4. CRL Production

Before issuing any certificates, a newly established CA (which issues CRLs) must produce "empty" versions of each CRL, which are to be periodically produced.

6.5. PKI Information Request

When a PKI entity (CA, RA, or EE) wishes to acquire information about the current status of a CA, it **MAY** send that CA a request for such information.

The CA **MUST** respond to the request by providing (at least) all of the information requested by the requester. If some of the information cannot be provided, then an error must be conveyed to the requester.

If PKIMessages are used to request and supply this PKI information, then the request **MUST** be the GenMsg message, the response **MUST** be the GenRep message, and the error **MUST** be the Error message. These messages are protected using a MAC based on shared secret information (e.g., password-based MAC; see [Section 6.1](#) of "CMP Algorithms" [[RFC9481](#)]) or using any asymmetric authentication means such as a signature (if the EE has an existing certificate).

6.6. Cross-Certification

The requester CA is the CA that will become the subject of the cross-certificate; the responder CA will become the issuer of the cross-certificate.

The requester CA must be "up and running" before initiating the cross-certification operation.

6.6.1. One-Way Request-Response Scheme

The cross-certification scheme is essentially a one-way operation; that is, when successful, this operation results in the creation of one new cross-certificate. If the requirement is that cross-certificates be created in "both directions", then each CA, in turn, must initiate a cross-certification operation (or use another scheme).

This scheme is suitable where the two CAs in question can already verify each other's signatures (they have some common points of trust) or where there is an out-of-band verification of the origin of the certification request.

Detailed Description:

Cross-certification is initiated at one CA known as the responder. The CA administrator for the responder identifies the CA it wants to cross-certify and the responder CA equipment generates an authorization code. The responder CA administrator passes this authorization code by out-of-band means to the requester CA administrator. The requester CA administrator enters the authorization code at the requester CA in order to initiate the online exchange.

The authorization code is used for authentication and integrity purposes. This is done by generating a symmetric key based on the authorization code and using the symmetric key for generating MACs on all messages exchanged. (Authentication may alternatively be done using signatures instead of MACs, if the CAs are able to retrieve and validate the required public keys by some means, such as an out-of-band hash comparison.)

The requester CA initiates the exchange by generating a cross-certification request (ccr) with a fresh random number (requester random number). The requester CA then sends the ccr message to the responder CA. The fields in this message are protected from modification with a MAC based on the authorization code.

Upon receipt of the ccr message, the responder CA validates the message and the MAC, saves the requester random number, and generates its own random number (responder random number). It then generates (and archives, if desired) a new requester certificate that contains the requester CA public key and is signed with the responder CA signature private key. The responder CA responds with the cross-certification response (ccp) message. The fields in this message are protected from modification with a MAC based on the authorization code.

Upon receipt of the ccp message, the requester CA validates the message (including the received random numbers) and the MAC. The requester CA responds with the certConf message. The fields in this message are protected from modification with a MAC based on the authorization code. The requester CA **MAY** write the requester certificate to the Repository as an aid to later certificate path construction.

Upon receipt of the certConf message, the responder CA validates the message and the MAC and sends back an acknowledgement using the pkiconf message. It **MAY** also publish the requester certificate as an aid to later path construction.

Notes:

1. The ccr message must contain a "complete" certification request; that is, all fields except the serial number (including, e.g., a BasicConstraints extension) must be specified by the requester CA.
2. The ccp message **SHOULD** contain the verification certificate of the responder CA; if present, the requester CA must then verify this certificate (for example, via the "out-of-band" mechanism).

(A simpler, non-interactive model of cross-certification may also be envisioned, in which the issuing CA acquires the subject CA's public key from some repository, verifies it via some out-of-band mechanism, and creates and publishes the cross-certificate without the subject CA's explicit involvement. This model may be perfectly legitimate for many environments, but since it does not require any protocol message exchanges, its detailed description is outside the scope of this specification.)

6.7. End Entity Initialization

As with CAs, EEs must be initialized. Initialization of EEs requires at least two steps:

- acquisition of PKI information
- out-of-band verification of one root-CA public key

(Other possible steps include the retrieval of trust condition information and/or out-of-band verification of other CA public keys.)

6.7.1. Acquisition of PKI Information

The information **REQUIRED** is:

- the current root-CA public key
- (if the certifying CA is not a root-CA) the certification path from the root CA to the certifying CA together with appropriate revocation lists
- the algorithms and algorithm parameters that the certifying CA supports for each relevant usage

Additional information could be required (e.g., supported extensions or CA policy information) in order to produce a certification request that will be successful. However, for simplicity, we do not mandate that the EE acquires this information via the PKI messages. The end result is simply that some certification requests may fail (e.g., if the EE wants to generate its own encryption key, but the CA doesn't allow that).

The required information **MAY** be acquired as described in [Section 6.5](#).

6.7.2. Out-of-Band Verification of the Root CA Key

An EE must securely possess the public key of its root CA. One method to achieve this is to provide the EE with the CA's self-certificate fingerprint via some secure "out-of-band" means. The EE can then securely use the CA's self-certificate.

See [Section 6.1](#) for further details.

6.8. Certificate Request

An initialized EE **MAY** request an additional certificate at any time (for any purpose). This request will be made using the certification request (cr) message. If the EE already possesses a signing key pair (with a corresponding verification certificate), then this cr message will typically be protected by the entity's digital signature. The CA returns the new certificate (if the request is successful) in a CertRepMessage.

6.9. Key Update

When a key pair is due to expire, the relevant EE **MAY** request a key update; that is, it **MAY** request that the CA issue a new certificate for a new key pair (or, in certain circumstances, a new certificate for the same key pair). The request is made using a key update request (kur) message (referred to, in some environments, as a "Certificate Update" operation). If the EE already possesses a signing key pair (with a corresponding verification certificate), then this message will typically be protected by the entity's digital signature. The CA returns the new certificate (if the request is successful) in a key update response (kup) message, which is syntactically identical to a CertRepMessage.

7. Version Negotiation

This section defines the version negotiation used to support older protocols between clients and servers.

If a client knows the protocol version(s) supported by the server (e.g., from a previous PKIMessage exchange or via some out-of-band means), then it **MUST** send a PKIMessage with the highest version supported by both it and the server. If a client does not know what version(s) the server supports, then it **MUST** send a PKIMessage using the highest version it supports with the following exception: Version cmp2021 **SHOULD** only be used if cmp2021 syntax is needed for the request being sent or for the expected response.

Note: Using cmp2000 as the default pvno is done to avoid extra message exchanges for version negotiation and to foster compatibility with cmp2000 implementations. Version cmp2021 syntax is only needed if a message exchange uses EnvelopedData, hashAlg (in CertStatus), POPOPrivKey with agreeMAC, or ckuann with RootCaKeyUpdateContent.

If a server receives a message with a version that it supports, then the version of the response message **MUST** be the same as the received version. If a server receives a message with a version higher or lower than it supports, then it **MUST** send back an ErrorMsg with the unsupportedVersion bit set (in the failureInfo field of the pKISStatusInfo). If the received version is higher than the highest supported version, then the version in the error message **MUST** be the highest version the server supports; if the received version is lower than the lowest supported version, then the version in the error message **MUST** be the lowest version the server supports.

If a client gets back an `ErrorMsgContent` with the `unsupportedVersion` bit set and a version it supports, then it **MAY** retry the request with that version.

7.1. Supporting RFC 2510 Implementations

[RFC2510] did not specify the behavior of implementations receiving versions they did not understand since there was only one version in existence. With the introduction of the revision in [RFC4210], the following versioning behavior is recommended.

7.1.1. Clients Talking to RFC 2510 Servers

If, after sending a message with a `pvno` higher than `cmp1999`, a client receives an `ErrorMsgContent` with a version of `cmp1999`, then it **MUST** abort the current transaction.

If a client receives a non-error `PKIMessage` with a version of `cmp1999`, then it **MAY** decide to continue the transaction (if the transaction hasn't finished) using the semantics described in [RFC2510]. If it does not choose to do so and the transaction is not finished, then it **MUST** abort the transaction and send an `ErrorMsgContent` with a version of `cmp1999`.

7.1.2. Servers Receiving Version `cmp1999` `PKIMessages`

If a server receives a version `cmp1999` message, it **MAY** revert to the behavior described in [RFC2510] and respond with version `cmp1999` messages. If it does not choose to do so, then it **MUST** send back an `ErrorMsgContent` as described above in [Section 7](#).

8. Security Considerations

8.1. On the Necessity of POP

It is well established that the role of a CA is to verify that the name and public key belong to the EE prior to issuing a certificate. If an entity holding a private key obtains a certificate containing the corresponding public key issued for a different entity, it can authenticate as the entity named in the certificate. This facilitates masquerading. It is not entirely clear what security guarantees are lost if an EE is able to obtain a certificate containing a public key that they do not possess the corresponding private key for. There are some scenarios, described as "forwarding attacks" in Appendix A of [Guenesysu], in which this can lead to protocol attacks against a naively implemented sign-then-encrypt protocol, but in general, it merely results in the EE obtaining a certificate that they cannot use.

8.2. POP with a Decryption Key

Some cryptographic considerations are worth explicitly spelling out. In the protocols specified above, when an EE is required to prove possession of a decryption key, it is effectively challenged to decrypt something (its own certificate). This scheme (and many others!) could be vulnerable to an attack if the possessor of the decryption key in question could be fooled into decrypting an arbitrary challenge and returning the cleartext to an attacker. Although in this specification a number of other failures in security are required in order for this attack to succeed, it is conceivable that some future services (e.g., notary, trusted time) could potentially

be vulnerable to such attacks. For this reason, we reiterate the general rule that implementations should be very careful about decrypting arbitrary "ciphertext" and revealing recovered "plaintext" since such a practice can lead to serious security vulnerabilities.

The client **MUST** return the decrypted values only if they match the expected content type. In an indirect method, the decrypted value **MUST** be a valid certificate, and in a direct method, the decrypted value **MUST** be a Rand as defined in [Section 5.2.8.3.3](#).

8.3. POP by Exposing the Private Key

Note also that exposing a private key to the CA/RA as a POP technique can carry some security risks (depending upon whether or not the CA/RA can be trusted to handle such material appropriately). Implementers are advised to:

- Exercise caution in selecting and using this particular POP mechanism.
- Only use this POP mechanism if archival of the private key is desired.
- When appropriate, have the user of the application explicitly state that they are willing to trust the CA/RA to have a copy of their private key before proceeding to reveal the private key.

8.4. Attack Against DH Key Exchange

A small subgroup attack during a DH key exchange may be carried out as follows. A malicious EE may deliberately choose DH parameters that enable it to derive (a significant number of bits of) the DH private key of the CA during a key archival or key recovery operation. Armed with this knowledge, the EE would then be able to retrieve the decryption private key of another unsuspecting EE, EE2, during EE2's legitimate key archival or key recovery operation with that CA. In order to avoid the possibility of such an attack, two courses of action are available. (1) The CA may generate a fresh DH key pair to be used as a protocol encryption key pair for each EE with which it interacts. (2) The CA may enter into a key validation protocol (not specified in this document) with each requesting EE to ensure that the EE's protocol encryption key pair will not facilitate this attack. Option (1) is clearly simpler (requiring no extra protocol exchanges from either party) and is therefore **RECOMMENDED**.

8.5. Perfect Forward Secrecy

Long-term security typically requires perfect forward secrecy (pfs). When transferring encrypted long-term confidential values such as centrally generated private keys or revocation passphrases, pfs is likely important. Yet, it is not needed for CMP message protection providing integrity and authenticity because transfer of PKI messages is usually completed in very limited time. For the same reason, it is not typically required for the indirect method to provide a POP ([Section 5.2.8.3.2](#)) delivering the newly issued certificate in encrypted form.

Encrypted values ([Section 5.2.2](#)) are transferred using CMS EnvelopedData [[RFC5652](#)], which does not offer pfs. In cases where long-term security is needed, CMP messages **SHOULD** be transferred over a mechanism that provides pfs, such as TLS with appropriate cipher suites selected.

8.6. Private Keys for Certificate Signing and CMP Message Protection

A CA should not reuse its certificate signing key for other purposes, such as protecting CMP responses and TLS connections. This way, exposure to other parts of the system and the number of uses of this particularly critical key are reduced to a minimum.

8.7. Entropy of Random Numbers, Key Pairs, and Shared Secret Information

Implementations must generate nonces and private keys from random input. The use of inadequate pseudorandom number generators (PRNGs) to generate cryptographic keys can result in little or no security. An attacker may find it much easier to reproduce the PRNG environment that produced the keys and to search the resulting small set of possibilities than brute-force searching the whole key space. As an example of predictable random numbers, see [CVE-2008-0166]; consequences of low-entropy random numbers are discussed in [Mining Your Ps and Qs](#) [MiningPsQs]. The generation of quality random numbers is difficult. ISO/IEC 20543:2019 [ISO.20543-2019], NIST SP 800-90A Rev.1 [NIST.SP.800_90Ar1], BSI AIS 31 V2.0 [AIS31], and other specifications offer valuable guidance in this area.

If shared secret information is generated by a cryptographically secure random number generator (CSRNG), it is safe to assume that the entropy of the shared secret information equals its bit length. If no CSRNG is used, the entropy of shared secret information depends on the details of the generation process and cannot be measured securely after it has been generated. If user-generated passwords are used as shared secret information, their entropy cannot be measured. Passwords generated from user generated entropy are typically insufficient for protected delivery of centrally generated keys or trust anchors.

If the entropy of shared secret information protecting the delivery of a centrally generated key pair is known, it should not be less than the security strength of that key pair; if the shared secret information is reused for different key pairs, the security of the shared secret information should exceed the security strength of each individual key pair.

For the case of a PKI management operation that delivers a new trust anchor (e.g., a root CA certificate), using caPubs or genp that is (a) not concluded in a timely manner or (b) where the shared secret information is reused for several key management operations, the entropy of the shared secret information, if known, should not be less than the security strength of the trust anchor being managed by the operation. The shared secret information should have an entropy that at least matches the security strength of the key material being managed by the operation. Certain use cases may require shared secret information that may be of a low security strength, e.g., a human-generated password. It is **RECOMMENDED** that such secret information be limited to a single PKI management operation.

Importantly for this section, further information about algorithm use profiles and their security strength is available in [Section 7](#) of CMP Algorithms [RFC9481].

8.8. Recurring Usage of KEM Keys for Message Protection

For each PKI management operation using MAC-based message protection involving KEM (see [Section 5.1.3.4](#)), the KEM Encapsulate() function, providing a fresh KEM ciphertext (ct) and shared secret (ss), **MUST** be invoked.

It is assumed that the overall data size of the CMP messages in a PKI management operation protected by a single shared secret key is small enough not to introduce extra security risks.

To be appropriate for use with this specification, the KEM algorithm **MUST** explicitly be designed to be secure when the public key is used many times. For example, a KEM algorithm with a single-use public key is not appropriate because the public key is expected to be carried in a long-lived certificate [[RFC5280](#)] and used over and over. Thus, KEM algorithms that offer indistinguishability under adaptive chosen ciphertext attack (IND-CCA2) security are appropriate. A common design pattern for obtaining IND-CCA2 security with public key reuse is to apply the Fujisaki-Okamoto (FO) transform [[Fujisaki](#)] or a variant of the FO transform [[Hofheinz](#)].

Therefore, given a long-term public key using an IND-CCA2-secure KEM algorithm, there is no limit to the number of CMP messages that can be authenticated using KEM keys for MAC-based message protection.

8.9. Trust Anchor Provisioning Using CMP Messages

A provider of trust anchors, which may be an RA involved in configuration management of its clients, **MUST NOT** include to-be-trusted CA certificates in a CMP message unless the specific deployment scenario can ensure that it is adequate that the receiving EE trusts these certificates, e.g., by loading them into its trust store.

Whenever an EE receives in a CMP message a CA certificate to be used as a trust anchor (for example, in the caPubs field of a certificate response or in a general response), it **MUST** properly authenticate the message sender with existing trust anchors without requiring new trust anchor information included in the message.

Additionally, the EE **MUST** verify that the sender is an authorized source of trust anchors. This authorization is governed by local policy and typically indicated using shared secret information or with a signature-based message protection using a certificate issued by a PKI that is explicitly authorized for this purpose.

8.10. Authorizing Requests for Certificates with Specific EKUs

When a CA issues a certificate containing EKU extensions as defined in [Section 4.5](#), this expresses delegation of an authorization that originally is only with the CA certificate itself. Such delegation is a very sensitive action in a PKI, and therefore, special care must be taken when approving such certificate requests to ensure that only legitimate entities receive a certificate containing such an EKU.

8.11. Usage of CT Logs

CAs that support indirect POP **MUST NOT** also publish final certificates to CT logs [RFC9162] before having received the certConf message containing the certHash of that certificate to complete the POP. The risk is that a malicious actor could fetch the final certificate from the CT log and use that to spoof a response to the implicit POP challenge via a certConf response. This risk does not apply to CT precertificates, so those are OK to publish.

If a certificate or its precertificate was published in a CT log, it must be revoked if a required certConf message could not be verified, especially when the implicit POP was used.

9. IANA Considerations

This document updates the ASN.1 modules in [Appendix A.2](#) of CMP Updates [RFC9480]. The OID 116 (id-mod-cmp2023-02) was registered in the "SMI Security for PKIX Module Identifier" registry to identify the updated ASN.1 module.

IANA has added the following entry in the "SMI Security for PKIX CMP Information Types" registry within the SMI Numbers registry group (see <<https://www.iana.org/assignments/smi-numbers>>) [RFC7299]:

Decimal: 24

Description: id-it-KemCiphertextInfo

Reference: RFC 9810

Note that the new OID 1.2.840.113533.7.66.16 was registered by Entrust, and not by IANA, for id-KemBasedMac in the arch 1.2.840.113533.7.66. This was done to match the previous registrations for id-PasswordBasedMac and id-DHBasedMac, which are also on the Entrust private arc.

All existing references to [RFC2510], [RFC4210], and [RFC9480] at <<https://www.iana.org/assignments/smi-numbers>> except those in the "SMI Security for PKIX Module Identifier" registry have been replaced with references to this document.

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Appendix A. Reasons for the Presence of RAs

The reasons that justify the presence of an RA can be split into those that are due to technical factors and those that are organizational in nature. Technical reasons include the following.

- If hardware tokens are in use, then not all EEs will have the equipment needed to initialize these; the RA equipment can include the necessary functionality (this may also be a matter of policy).
- Some EEs may not have the capability to publish certificates; again, the RA may be suitably placed for this.
- The RA will be able to issue signed revocation requests on behalf of EEs associated with it, whereas the EE may not be able to do this (if the key pair is completely lost).

Some of the organizational reasons that argue for the presence of an RA are the following.

- It may be more cost effective to concentrate functionality in the RA equipment than to supply functionality to all EEs (especially if special token initialization equipment is to be used).
- Establishing RAs within an organization can reduce the number of CAs required, which is sometimes desirable.
- RAs may be better placed to identify people with their "electronic" names, especially if the CA is physically remote from the EE.
- For many applications, there will already be some administrative structure in place so that candidates for the role of RA are easy to find (which may not be true of the CA).

Further reasons relevant for automated machine-to-machine certificate lifecycle management are available in the Lightweight CMP Profile [RFC9483].

Appendix B. The Use of Revocation Passphrase

A revocation request must incorporate suitable security mechanisms, including proper authentication, in order to reduce the probability of successful denial-of-service attacks. A digital signature or DH/KEM-based message protection on the request -- **REQUIRED** to support within this specification depending on the key type used if revocation requests are supported -- can provide the authentication required, but there are circumstances under which an alternative mechanism may be desirable (e.g., when the private key is no longer accessible and the entity wishes to request a revocation prior to re-certification of another key pair). In order to accommodate such circumstances, a password-based MAC (see [Section 6.1](#) of CMP Algorithms [[RFC9481](#)]) on the request is also **REQUIRED** to support within this specification (subject to local security policy for a given environment) if revocation requests are supported and if shared secret information can be established between the requester and the responder prior to the need for revocation.

A mechanism that has seen use in some environments is "revocation passphrase", in which a value of sufficient entropy (i.e., a relatively long passphrase rather than a short password) is shared between (only) the entity and the CA/RA at some point prior to revocation; this value is later used to authenticate the revocation request.

In this specification, the following technique to establish shared secret information (i.e., a revocation passphrase) is **OPTIONAL** to support. Its precise use in CMP messages is as follows.

- The OID and value specified in [Section 5.3.19.9](#) **MAY** be sent in a GenMsg message at any time or **MAY** be sent in the generalInfo field of the PKIHeader of any PKIMessage at any time. (In particular, the EncryptedKey structure as described in [Section 5.2.2](#) may be sent in the header of the certConf message that confirms acceptance of certificates requested in an initialization request or certificate request message.) This conveys a revocation passphrase chosen by the entity to the relevant CA/RA. When EnvelopedData is used, this is in the decrypted bytes of the encryptedContent field. When EncryptedValue is used, this is in the decrypted bytes of the encValue field. Furthermore, the transfer is accomplished with appropriate confidentiality characteristics.
- If a CA/RA receives the revocation passphrase (OID and value specified in [Section 5.3.19.9](#)) in a GenMsg, it **MUST** construct and send a GenRep message that includes the OID (with absent value) specified in [Section 5.3.19.9](#). If the CA/RA receives the revocation passphrase in the generalInfo field of a PKIHeader of any PKIMessage, it **MUST** include the OID (with absent value) in the generalInfo field of the PKIHeader of the corresponding response PKIMessage. If the CA/RA is unable to return the appropriate response message for any reason, it **MUST** send an error message with a status of "rejection" and, optionally, a failInfo reason set.
- Either the localKeyId attribute of EnvelopedData as specified in [[RFC2985](#)] or the valueHint field of EncryptedValue **MAY** contain a key identifier (chosen by the entity, along with the passphrase itself) to assist in later retrieval of the correct passphrase (e.g., when the revocation request is constructed by the EE and received by the CA/RA).

- The revocation request message is protected by a password-based MAC (see [Section 6.1](#) of "CMP Algorithms" [[RFC9481](#)]) with the revocation passphrase as the key. If appropriate, the senderKID field in the PKIHeader **MAY** contain the value previously transmitted in localKeyId or valueHint.

Note: For a message transferring a revocation passphrase indicating cmp2021(3) in the pvno field of the PKIHeader, the encrypted passphrase **MUST** be transferred in the envelopedData choice of EncryptedKey as defined in [Section 5.2.2](#). When using cmp2000(2) in the message header for backward compatibility, the encryptedValue is used. This allows the necessary conveyance and protection of the passphrase while maintaining bits-on-the-wire compatibility with [[RFC4210](#)]. The encryptedValue choice has been deprecated in favor of encryptedData.

Using the technique specified above, the revocation passphrase may be initially established and updated at any time without requiring extra messages or out-of-band exchanges. For example, the revocation request message itself (protected and authenticated through a MAC that uses the revocation passphrase as a key) may contain, in the PKIHeader, a new revocation passphrase to be used for authenticating future revocation requests for any of the entity's other certificates. In some environments, this may be preferable to mechanisms that reveal the passphrase in the revocation request message, since this can allow a denial-of-service attack in which the revealed passphrase is used by an unauthorized third party to authenticate revocation requests on the entity's other certificates. However, because the passphrase is not revealed in the request message, there is no requirement that the passphrase must always be updated when a revocation request is made (that is, the same passphrase **MAY** be used by an entity to authenticate revocation requests for different certificates at different times).

Furthermore, the above technique can provide strong cryptographic protection over the entire revocation request message even when a digital signature is not used. Techniques that do authentication of the revocation request by simply revealing the revocation passphrase typically do not provide cryptographic protection over the fields of the request message (so that a request for revocation of one certificate may be modified by an unauthorized third party to a request for revocation of another certificate for that entity).

Appendix C. PKI Management Message Profiles (REQUIRED)

This appendix contains detailed profiles for those PKIMessages that **MUST** be supported by conforming implementations (see [Section 6](#)).

Note: Appendices [C](#) and [D](#) focus on PKI management operations managing certificates for human EEs. In contrast, the Lightweight CMP Profile [[RFC9483](#)] focuses on typical use cases of industrial and IoT scenarios supporting highly automated certificate lifecycle management scenarios.

Profiles for the PKIMessages used in the following PKI management operations are provided:

- initial registration/certification
- basic authenticated scheme

- certificate request
- key update

C.1. General Rules for Interpretation of These Profiles

1. Where **OPTIONAL** or **DEFAULT** fields are not mentioned in individual profiles, they **SHOULD** be absent from the relevant message (i.e., a receiver can validly reject a message containing such fields as being syntactically incorrect). Mandatory fields are not mentioned if they have an obvious value. The **pvno** **MUST** be set as specified in [Section 7](#)).
2. Where structures occur in more than one message, they are separately profiled as appropriate.
3. The `algorithmIdentifiers` from `PKIMessage` structures are profiled separately.
4. A "special" X.500 DN is called the "NULL-DN"; this means a DN containing a zero-length `SEQUENCE OF RelativeDistinguishedNames` (its DER encoding is then '3000'H).
5. Where a `GeneralName` is required for a field, but no suitable value is available (e.g., an EE produces a request before knowing its name), then the `GeneralName` is to be an X.500 NULL-DN (i.e., the `Name` field of the `CHOICE` is to contain a NULL-DN).
6. Where a profile omits to specify the value for a `GeneralName`, then the NULL-DN value is to be present in the relevant `PKIMessage` field. This occurs with the sender field of the `PKIHeader` for some messages.
7. Where any ambiguity arises due to naming of fields, the profile names these using a "dot" notation (e.g., "certTemplate.subject" means the subject field within a field called certTemplate).
8. Where a "SEQUENCE OF types" is part of a message, a zero-based array notation is used to describe fields within the SEQUENCE OF (e.g., `crm[0].certReq.certTemplate.subject` refers to a subfield of the first `CertReqMsg` contained in a request message).
9. All PKI message exchanges in Appendices [C.4](#) to [C.6](#) require a `certConf` message to be sent by the initiating entity and a `pkiconf` message to be sent by the responding entity. The `pkiconf` is not included in some of the profiles given since its body is NULL and its header contents are clear from the context. Any authenticated means can be used for the `protectionAlg` (e.g., password-based MAC, if shared secret information is known, or signature).

C.2. Algorithm Use Profile

For specifications of algorithm identifiers and respective conventions for conforming implementations, please refer to [Section 7.1](#) of CMP Algorithms [\[RFC9481\]](#).

C.3. POP Profile

The table below describes the POP fields for use (in signature field of pop field of `ProofOfPossession` structure) when proving possession of a private signing key that corresponds to a public verification key for which a certificate has been requested.

Field	Value	Comment
algorithmIdentifier	MSG_SIG_ALG	only signature protection is allowed for this proof
signature	present	bits calculated using MSG_SIG_ALG

Table 2

Note: For examples of MSG_SIG_ALG OIDs, see [Section 3](#) of CMP Algorithms [RFC9481].

POP of a private decryption key that corresponds to a public encryption key for which a certificate has been requested does not use this profile; the CertHash field of the certConf message is used instead.

Not every CA/RA will do POP (of signing key, decryption key, or key agreement key) in the PKIX-CMP in-band certification request protocol (how POP is done **MAY** ultimately be a policy issue that is made explicit for any given CA in its publicized Policy OID and Certification Practice Statement). However, this specification mandates that CA/RA entities **MUST** do POP (by some means) as part of the certification process. All EEs **MUST** be prepared to provide POP (i.e., these components of the PKIX-CMP protocol **MUST** be supported).

C.4. Initial Registration/Certification (Basic Authenticated Scheme)

An (uninitialized) EE requests a (first) certificate from a CA. When the CA responds with a message containing a certificate, the EE replies with a certificate confirmation. The CA sends a pkiconf message back, closing the transaction. All messages are authenticated.

This scheme allows the EE to request certification of a locally generated public key (typically a signature key). The EE **MAY** also choose to request the centralized generation and certification of another key pair (typically an encryption key pair).

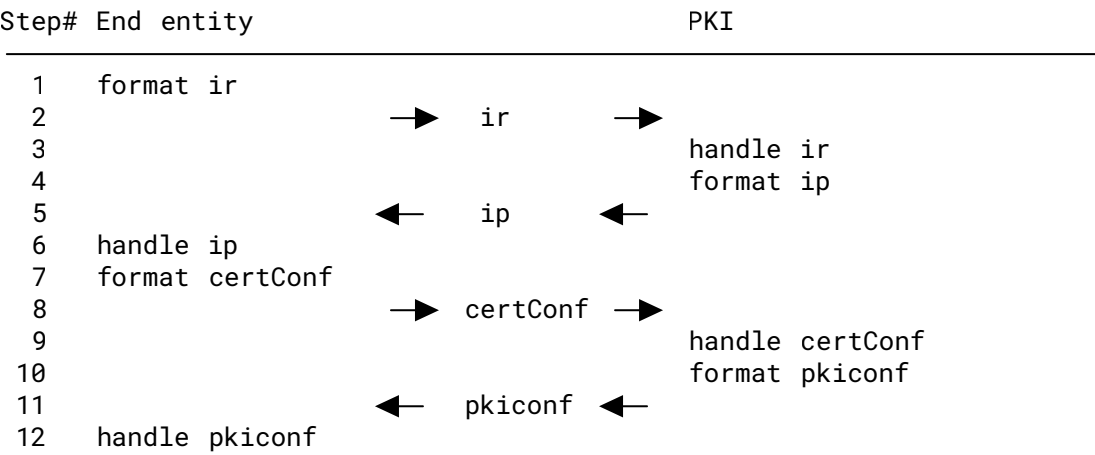
Certification may only be requested for one locally generated public key (for more, use separate PKIMessages).

The EE **MUST** support POP of the private key associated with the locally generated public key.

Preconditions:

1. The EE can authenticate the CA's signature based on out-of-band means.
2. The EE and the CA share a symmetric MACing key.

Message Flow:



For this profile, we mandate that the EE **MUST** include all (i.e., one or two) CertReqMsg in a single PKIMessage and that the PKI (CA) **MUST** produce a single response PKIMessage that contains the complete response (i.e., including the **OPTIONAL** second key pair, if it was requested and if centralized key generation is supported). For simplicity, we also mandate that this message **MUST** be the final one (i.e., no use of "waiting" status value).

The EE has an out-of-band interaction with the CA/RA. This transaction established the shared secret, the referenceNumber, and optionally the DN used for both the sender and subject name in the certificate template. See [Section 8.7](#) for security considerations on quality of shared secret information.

Initialization Request -- ir

Field	Value
recipient	CA name -- the name of the CA who is being asked to produce a certificate
protectionAlg	MSG_MAC_ALG -- only MAC protection is allowed for this request, based -- on initial authentication key
senderKID	referenceNum -- the reference number that the CA has previously issued -- to the EE (together with the MACing key)
transactionID	present -- implementation-specific value, meaningful to end -- entity. -- [If already in use at the CA, then a rejection message MUST -- be produced by the CA]
senderNonce	present -- 128 (pseudo-)random bits
freeText	any valid value
body	ir (CertReqMessages) only one or two CertReqMsg are allowed -- if more certificates are required, requests MUST be -- packaged in separate PKIMessages
CertReqMsg	one or two present -- see below for details, note: crm[0] means the first -- (which MUST be present), crm[1] means the second (which -- is OPTIONAL, and used to ask for a centrally generated key)
crm[0].certReq.	fixed value of zero
certReqId	 -- this is the index of the template within the message
crm[0].certReq	present
certTemplate	 -- MUST include subject public key value, otherwise unconstrained
crm[0].pop...	optionally present if public key
POPOSigningKey	from crm[0].certReq.certTemplate is a signing key -- POP MAY be required in this exchange -- (see Appendix D.3 for details)
crm[0].certReq.	optionally present
controls.archiveOptions	 -- the EE MAY request that the locally generated -- private key be archived
crm[0].certReq.	optionally present
controls.publicationInfo	 -- the EE MAY ask for publication of resulting cert.
crm[1].certReq	fixed value of one
certReqId	 -- the index of the template within the message
crm[1].certReq	present
certTemplate	 -- MUST NOT include actual public key bits, otherwise -- unconstrained (e.g., the names need not be the same as in

```
-- crm[0]). Note that subjectPublicKeyInfo MAY be present
-- and contain an AlgorithmIdentifier followed by a
-- zero-length BIT STRING for the subjectPublicKey if it is
-- desired to inform the CA/RA of algorithm and parameter
-- preferences regarding the to-be-generated key pair.

crm[1].certReq.      present [object identifier MUST be
                        PROT_ENC_ALG]

    controls.protocolEncrKey
-- if centralized key generation is supported by this CA,
-- this short-term asymmetric encryption key (generated by
-- the EE) will be used by the CA to encrypt (a
-- symmetric key used to encrypt) a private key generated by
-- the CA on behalf of the EE

crm[1].certReq.      optionally present
    controls.archiveOptions
crm[1].certReq.      optionally present
    controls.publicationInfo
protection           present
-- bits calculated using MSG_MAC_ALG
```

Initialization Response -- ip

Field	Value
sender	CA name
	-- the name of the CA who produced the message
messageTime	present
	-- time at which CA produced message
protectionAlg	MSG_MAC_ALG
	-- only MAC protection is allowed for this response
senderKID	referenceNum
	-- the reference number that the CA has previously issued to the
	-- EE (together with the MACing key)
transactionID	present
	-- value from corresponding ir message
senderNonce	present
	-- 128 (pseudo-)random bits
recipNonce	present
	-- value from senderNonce in corresponding ir message
freeText	any valid value
body	ip (CertRepMessage)
	contains exactly one response
	for each request
	-- The PKI (CA) responds to either one or two requests as
	-- appropriate. crc[0] denotes the first (always present);
	-- crc[1] denotes the second (only present if the ir message
	-- contained two requests and if the CA supports centralized
	-- key generation).
crc[0].	fixed value of zero
certReqId	
	-- MUST contain the response to the first request in the
	-- corresponding ir message
crc[0].status.	present, positive values allowed:
status	"accepted", "grantedWithMods"
	negative values allowed:
	"rejection"
crc[0].status.	present if and only if
failInfo	crc[0].status.status is "rejection"
crc[0].	present if and only if
certifiedKeyPair	crc[0].status.status is
	"accepted" or "grantedWithMods"
certificate	present unless end entity's public
	key is an encryption key and POP
	is done in this in-band exchange
encryptedCert	present if and only if end entity's
	public key is an encryption key and
	POP done in this in-band exchange
publicationInfo	optionally present
	-- indicates where certificate has been published (present
	-- at discretion of CA)
crc[1].	fixed value of one
certReqId	
	-- MUST contain the response to the second request in the
	-- corresponding ir message
crc[1].status.	present, positive values allowed:
status	"accepted", "grantedWithMods"
	negative values allowed:


```

                                "rejection"
crc[1].status.                  present if and only if
  failInfo                      crc[0].status.status is "rejection"
crc[1].                          present if and only if
  certifiedKeyPair              crc[0].status.status is "accepted"
                                or "grantedWithMods"
certificate                     present
privateKey                     present
  -- Use EnvelopedData; if backward compatibility is required,
  -- use EncryptedValue, see Section 5.2.2
publicationInfo                optionally present
  -- indicates where certificate has been published (present
  -- at discretion of CA)

protection                     present
  -- bits calculated using MSG_MAC_ALG
extraCerts                     optionally present
  -- the CA MAY provide additional certificates to the end
  -- entity

```

Certificate confirm -- certConf

Field	Value
sender	present
-- same as in ir	
recipient	CA name
-- the name of the CA who was asked to produce a certificate	
transactionID	present
-- value from corresponding ir and ip messages	
senderNonce	present
-- 128 (pseudo-)random bits	
recipNonce	present
-- value from senderNonce in corresponding ip message	
protectionAlg	MSG_MAC_ALG
-- only MAC protection is allowed for this message. The	
-- MAC is based on the initial authentication key shared	
-- between the EE and the CA.	
senderKID	referenceNum
-- the reference number that the CA has previously issued	
-- to the EE (together with the MACing key)	
body	certConf
-- see Section 5.3.18, "PKI Confirmation Content", for the	
-- contents of the certConf fields.	
-- Note: two CertStatus structures are required if both an	
-- encryption and a signing certificate were sent.	
protection	present
-- bits calculated using MSG_MAC_ALG	

Confirmation -- pkiconf

Field	Value
sender	present
-- same as in ip	
recipient	present
-- sender name from certConf	
transactionID	present
-- value from certConf message	
senderNonce	present
-- 128 (pseudo-)random bits	
recipNonce	present
-- value from senderNonce from certConf message	
protectionAlg	MSG_MAC_ALG
-- only MAC protection is allowed for this message.	
senderKID	referenceNum
body	pkiconf
protection	present
-- bits calculated using MSG_MAC_ALG	

C.5. Certificate Request

An (initialized) EE requests a certificate from a CA (for any reason). When the CA responds with a message containing a certificate, the EE replies with a certificate confirmation. The CA replies with a pkiconf message to close the transaction. All messages are authenticated.

The profile for this exchange is identical to that given in [Appendix C.4](#), with the following exceptions:

- sender name **SHOULD** be present;
- protectionAlg of MSG_SIG_ALG **MUST** be supported (MSG_MAC_ALG **MAY** also be supported) in request, response, certConf, and pkiconf messages;
- senderKID and recipKID are only present if required for message verification;
- body is cr or cp;
- body may contain one or two CertReqMsg structures, but either CertReqMsg may be used to request certification of a locally generated public key or a centrally generated public key (i.e., the position-dependence requirement of [Appendix C.4](#) is removed); and
- protection bits are calculated according to the protectionAlg field.

C.6. Key Update Request

An (initialized) EE requests a certificate from a CA (to update the key pair and/or corresponding certificate that it already possesses). When the CA responds with a message containing a certificate, the EE replies with a certificate confirmation. The CA replies with a PKIConfirm to close the transaction. All messages are authenticated.

The profile for this exchange is identical to that given in [Appendix C.4](#), with the following exceptions:

- sender name **SHOULD** be present;

- protectionAlg of MSG_SIG_ALG **MUST** be supported (MSG_MAC_ALG **MAY** also be supported) in request, response, certConfirm, and PKIConfirm messages;
- senderKID and recipKID are only present if required for message verification;
- body is kur or kup;
- body may contain one or two CertReqMsg structures, but either CertReqMsg may be used to request certification of a locally generated public key or a centrally generated public key (i.e., the position-dependence requirement of [Appendix C.4](#) is removed);
- protection bits are calculated according to the protectionAlg field; and
- regCtrl OldCertId **SHOULD** be used (unless it is clear to both the sender and receiver -- by means not specified in this document -- that it is not needed).

Appendix D. PKI Management Message Profiles (OPTIONAL)

This appendix contains detailed profiles for those PKIMessages that **MAY** be supported by implementations.

Profiles for the PKIMessages used in the following PKI management operations are provided:

- root CA key update
- information request/response
- cross-certification request/response (1-way)
- in-band initialization using external identity certificate

Future versions of this document may extend the above to include profiles for the operations listed below (along with other operations, if desired).

- revocation request
- certificate publication
- CRL publication

D.1. General Rules for Interpretation of These Profiles

Identical to [Appendix C.1](#).

D.2. Algorithm Use Profile

Identical to [Appendix C.2](#).

D.3. Self-Signed Certificates

The table below is a profile of how a certificate structure may be "self-signed". These structures are used for distribution of new root CA public keys. This can occur in one of three ways (see [Section 4.4](#) above for a description of the use of these structures):

Type	Function
newWithNew	a "self-signed" certificate; the contained public key MUST be usable to verify the signature (though this provides only integrity and no authentication whatsoever)
oldWithNew	previous root CA public key signed with new private key
newWithOld	new root CA public key signed with previous private key

Table 3

A newWithNew certificate (including relevant extensions) must contain "sensible" values for all fields. For example, when present, subjectAltName **MUST** be identical to issuerAltName, and, when present, keyIdentifiers must contain appropriate values, et cetera.

D.4. Root CA Key Update

A root CA updates its key pair. It then produces a CA key update announcement message that can be made available (via some transport mechanism) to the relevant EEs. A confirmation message is not required from the EEs.

ckuann message:

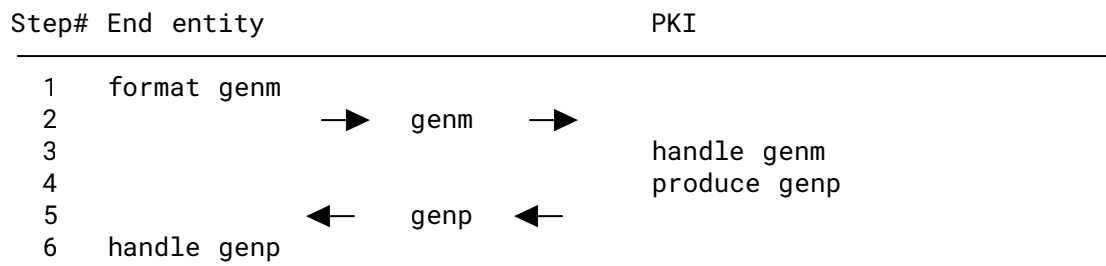
Field	Value	Comment
sender	CA name CA name	
body	ckuann(RootCaKeyUpdateContent)	
newWithNew	optionally present	see Appendix D.3 above
newWithOld	optionally present	see Appendix D.3 above
oldWithNew	optionally present	see Appendix D.3 above
extraCerts	optionally present	can be used to "publish" certificates (e.g., certificates signed using the new private key)

Table 4

D.5. PKI Information Request/Response

The EE sends a general message to the PKI requesting details that will be required for later PKI management operations. The RA/CA responds with a general response. If an RA generates the response, then it will simply forward the equivalent message that it previously received from the CA, with the possible addition of certificates to the extraCerts fields of the PKIMessage. A confirmation message is not required from the EE.

Message Flows:



genM:

Field	Value
recipient	CA name
	-- the name of the CA as contained in issuerAltName
	-- extensions or issuer fields within certificates
protectionAlg	MSG_MAC_ALG or MSG_SIG_ALG
	-- any authenticated protection alg.
SenderKID	present if required
	-- must be present if required for verification of message
	-- protection
freeText	any valid value
body	genr (GenReqContent)
GenMsgContent	empty SEQUENCE
	-- all relevant information requested
protection	present
	-- bits calculated using MSG_MAC_ALG or MSG_SIG_ALG

genP:

Field	Value
sender	CA name -- name of the CA that produced the message
protectionAlg	MSG_MAC_ALG or MSG_SIG_ALG -- any authenticated protection alg.
senderKID	present if required -- must be present if required for verification of message -- protection
body	genp (GenRepContent)
CAProtEncCert	present (object identifier one of PROT_ENC_ALG), with relevant value -- to be used if EE needs to encrypt information for the CA (e.g., private key for recovery purposes)
SignKeyPairTypes	present, with relevant value -- the set of signature algorithm identifiers that this CA will certify for subject public keys
EncKeyPairTypes	present, with relevant value -- the set of encryption / key agreement algorithm identifiers that this CA will certify for subject public keys
PreferredSymmAlg	present (object identifier one of PROT_SYM_ALG) , with relevant value -- the symmetric algorithm that this CA expects to be used in later PKI messages (for encryption)
RootCaKeyUpdate	optionally present, with relevant value -- Use RootCaKeyUpdate; if backward compatibility with cmp2000 is required, use CAKeyUpdateInfo. -- The CA MAY provide information about a relevant root CA key pair using this field (note that this does not imply that the responding CA is the root CA in question)
CurrentCRL	optionally present, with relevant value -- the CA MAY provide a copy of a complete CRL (i.e., fullest possible one)
protection	present -- bits calculated using MSG_MAC_ALG or MSG_SIG_ALG
extraCerts	optionally present -- can be used to send some certificates to the end entity. An RA MAY add its certificate here.

D.6. Cross-Certification Request/Response (1-way)

This section describes the creation of a single cross-certificate (i.e., not two at once). The requesting CA **MAY** choose who is responsible for publication of the cross-certificate created by the responding CA through use of the PKIPublicationInfo control.

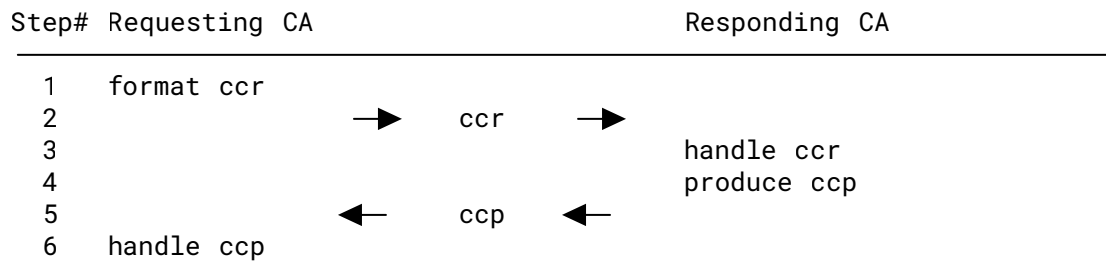
Preconditions:

1. Responding CA can verify the origin of the request (possibly requiring out-of-band means) before processing the request.

2. Requesting CA can authenticate the authenticity of the origin of the response (possibly requiring out-of-band means) before processing the response.

The use of certificate confirmation and the corresponding server confirmation is determined by the `generalInfo` field in the `PKIHeader` (see [Section 5.1.1](#)). The following profile does not mandate support for either confirmation.

Message Flows:



ccr:

Field	Value
sender	Requesting CA name
-- the name of the CA who produced the message	
recipient	Responding CA name
-- the name of the CA who is being asked to produce a certificate	
messageTime	time of production of message
-- current time at requesting CA	
protectionAlg	MSG_SIG_ALG
-- only signature protection is allowed for this request	
senderKID	present if required
-- must be present if required for verification of message	
-- protection	
recipKID	present if required
-- must be present if required for verification of message	
-- protection	
transactionID	present
-- implementation-specific value, meaningful to requesting CA.	
-- [If already in use at responding CA, then a rejection message	
-- MUST be produced by responding CA]	
senderNonce	present
-- 128 (pseudo-)random bits	
freeText	any valid value
body	ccr (CertReqMessages)
	only one CertReqMsg
	allowed
-- if multiple cross-certificates are required, they MUST be	
-- packaged in separate PKIMessages	
certTemplate	present
-- details follow	
version	v1 or v3
-- v3 STRONGLY RECOMMENDED	
signingAlg	present
-- the requesting CA must know in advance with which algorithm it	
-- wishes the certificate to be signed	
subject	present
-- may be NULL-DN only if subjectAltNames extension value proposed	
validity	present
-- MUST be completely specified (i.e., both fields present)	
issuer	present
-- may be NULL-DN only if issuerAltNames extension value proposed	
publicKey	present
-- the key to be certified (which must be for a signing algorithm)	
extensions	optionally present
-- a requesting CA must propose values for all extensions	
-- that it requires to be in the cross-certificate	
POPOSigningKey	present
-- see Appendix C.3: POP Profile	
protection	present
-- bits calculated using MSG_SIG_ALG	
extraCerts	optionally present
-- MAY contain any additional certificates that requester wishes	
-- to include	

ccp:

Field	Value
sender	Responding CA name
-- the name of the CA who produced the message	
recipient	Requesting CA name
-- the name of the CA who asked for production of a certificate	
messageTime	time of production of message
-- current time at responding CA	
protectionAlg	MSG_SIG_ALG
-- only signature protection is allowed for this message	
senderKID	present if required
-- must be present if required for verification of message	
-- protection	
recipKID	present if required
transactionID	present
-- value from corresponding ccr message	
senderNonce	present
-- 128 (pseudo-)random bits	
recipNonce	present
-- senderNonce from corresponding ccr message	
freeText	any valid value
body	ccp (CertRepMessage)
-- only one CertResponse allowed	
-- if multiple cross-certificates are required, they MUST be	
-- packaged in separate PKIMessages	
response	present
status	present
PKIStatusInfo.status	present
-- if PKIStatusInfo.status is one of:	
-- accepted, or	
-- grantedWithMods,	
-- then certifiedKeyPair MUST be present and failInfo MUST	
-- be absent	
failInfo	present depending on PKIStatusInfo.status
-- if PKIStatusInfo.status is:	
-- rejection,	
-- then certifiedKeyPair MUST be absent and failInfo MUST be	
-- present and contain appropriate bit settings	
certifiedKeyPair	present depending on PKIStatusInfo.status
certificate	present depending on certifiedKeyPair
-- content of actual certificate must be examined by requesting CA	
-- before publication	
protection	present
-- bits calculated using MSG_SIG_ALG	
extraCerts	optionally present
-- MAY contain any additional certificates that responder wishes	
-- to include	

D.7. In-Band Initialization Using External Identity Certificate

An (uninitialized) EE wishes to initialize into the PKI with a CA, CA-1. It uses, for authentication purposes, a pre-existing identity certificate issued by another (external) CA, CA-X. A trust relationship must already have been established between CA-1 and CA-X so that CA-1 can validate the EE identity certificate signed by CA-X. Furthermore, some mechanism must already have been established within the TEE, also known as PSE, of the EE that would allow it to authenticate and verify PKIMessages signed by CA-1 (as one example, the TEE may contain a certificate issued for the public key of CA-1, signed by another CA that the EE trusts on the basis of out-of-band authentication techniques).

The EE sends an initialization request to start the transaction. When CA-1 responds with a message containing the new certificate, the EE replies with a certificate confirmation. CA-1 replies with a pkiconf message to close the transaction. All messages are signed (the EE messages are signed using the private key that corresponds to the public key in its external identity certificate; the CA-1 messages are signed using the private key that corresponds to the public key in a certificate that can be chained to a trust anchor in the EE's TEE).

The profile for this exchange is identical to that given in [Appendix C.4](#), with the following exceptions:

- the EE and CA-1 do not share a symmetric MACing key (i.e., there is no out-of-band shared secret information between these entities);
- sender name in ir **MUST** be present (and identical to the subject name present in the external identity certificate);
- protectionAlg of MSG_SIG_ALG **MUST** be used in all messages;
- external identity certificate **MUST** be carried in ir extraCerts field
- senderKID and recipKID are not used;
- body is ir or ip; and
- protection bits are calculated according to the protectionAlg field.

Appendix E. Variants of Using KEM Keys for PKI Message Protection

As described in [Section 5.1.3.4](#), any party in a PKI management operation may wish to use a KEM key pair for message protection. Possible cases are described below.

For any PKI management operation started by a PKI entity with any type of request message, the following message flows describe the use of a KEM key. There are two cases to distinguish, namely whether the PKI entity or the PKI management entity owns a KEM key pair. If both sides own KEM key pairs, the flows need to be combined such that for each direction a shared secret key is established.

In the following message flows, Alice indicates the PKI entity that uses a KEM key pair for message authentication and Bob provides the KEM ciphertext using Alice's public KEM key, as described in [Section 5.1.3.4](#).

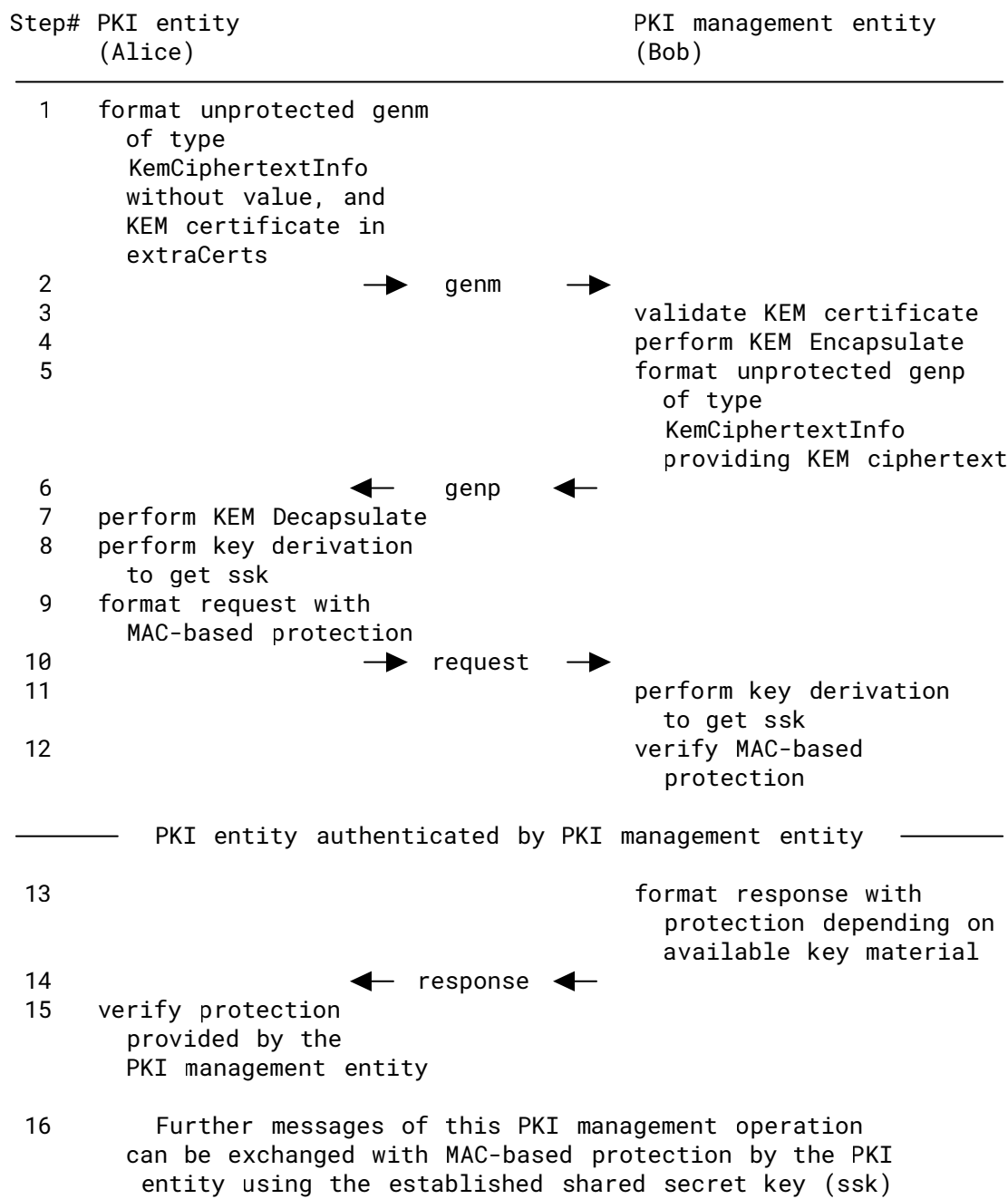


Figure 3: Message Flow When the PKI Entity Has a KEM Key Pair and Certificate

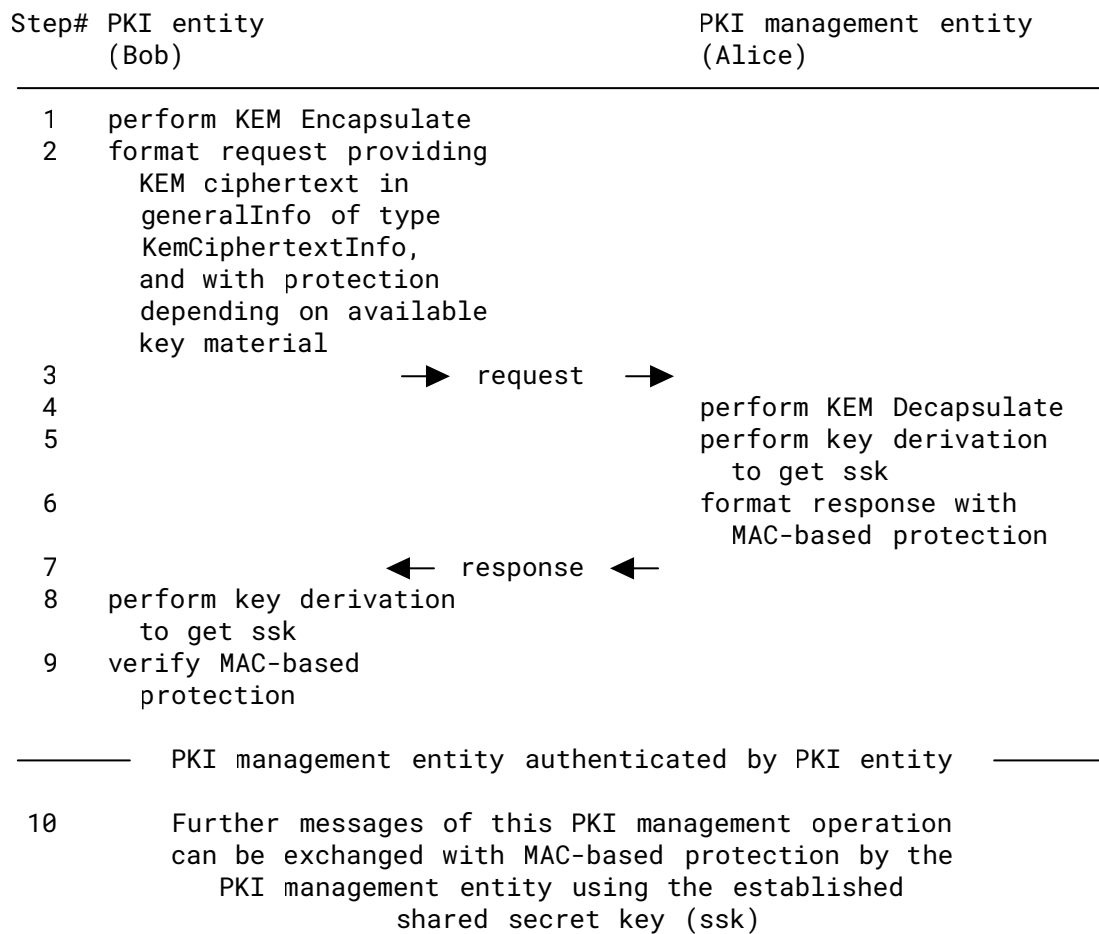


Figure 4: Message Flow When the PKI Entity Knows That the PKI Management Entity Uses a KEM Key Pair and Has the Authentic Public Key

Note: [Figure 4](#) describes the situation where KEM-based message protection may not require more than one message exchange. In this case, the transactionID **MUST** also be used by the PKI entity (Bob) to ensure domain separation between different PKI management operations.

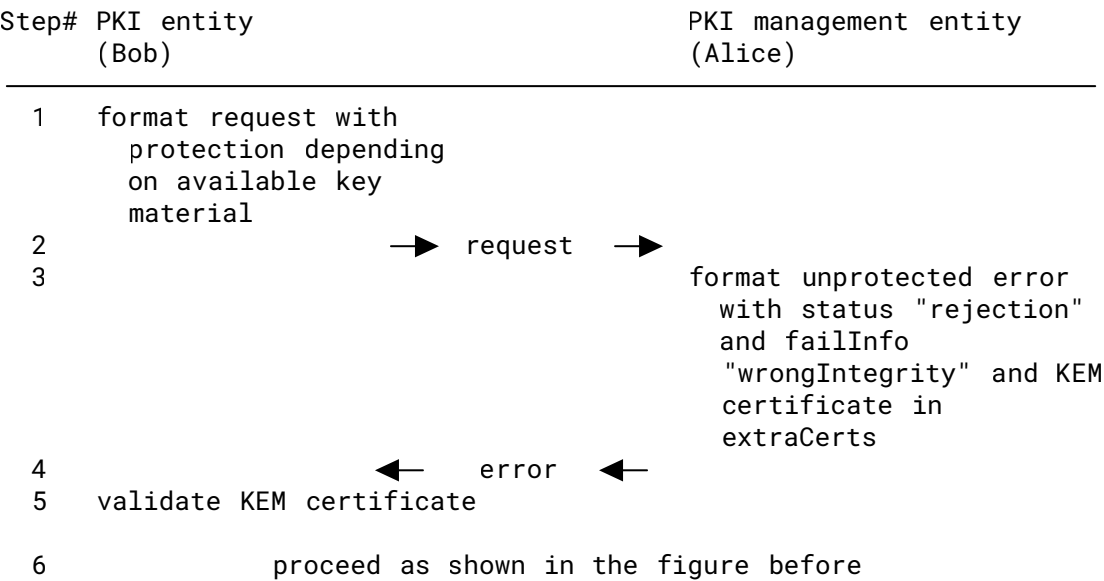


Figure 5: Message Flow When the PKI Entity Does Not Know That the PKI Management Entity Uses a KEM Key Pair

Appendix F. Compilable ASN.1 Definitions

This section contains the updated 2002 ASN.1 module from [RFC5912], which was updated in [RFC9480]. This module replaces the module in Section 9 of [RFC5912]. The module contains those changes to the normative ASN.1 module from Appendix F of [RFC4210] that were specified in [RFC9480], as well as changes made in this document. This module makes reference to ASN.1 structures defined in [RFC6268], as well as the UTF-8 encoding defined in [RFC3629].

```
PKIXCMP-2023
{ iso(1) identified-organization(3) dod(6) internet(1)
  security(5) mechanisms(5) pkix(7) id-mod(0)
  id-mod-cmp2023-02(116) }
DEFINITIONS EXPLICIT TAGS ::=
BEGIN
IMPORTS

AttributeSet{}, SingleAttribute{}, Extensions{}, EXTENSION, ATTRIBUTE
FROM PKIX-CommonTypes-2009
  {iso(1) identified-organization(3) dod(6) internet(1) security(5)
  mechanisms(5) pkix(7) id-mod(0) id-mod-pkixCommon-02(57)}

AlgorithmIdentifier{}, SIGNATURE-ALGORITHM, ALGORITHM,
DIGEST-ALGORITHM, MAC-ALGORITHM, KEY-DERIVATION
FROM AlgorithmInformation-2009
  {iso(1) identified-organization(3) dod(6) internet(1) security(5)
  mechanisms(5) pkix(7) id-mod(0)
  id-mod-algorithmInformation-02(58)}
```

```

Certificate, CertificateList, Time, id-kp
FROM PKIX1Explicit-2009
    {iso(1) identified-organization(3) dod(6) internet(1) security(5)
      mechanisms(5) pkix(7) id-mod(0) id-mod-pkix1-explicit-02(51)}

DistributionPointName, GeneralNames, GeneralName, KeyIdentifier
FROM PKIX1Implicit-2009
    {iso(1) identified-organization(3) dod(6) internet(1) security(5)
      mechanisms(5) pkix(7) id-mod(0) id-mod-pkix1-implicit-02(59)}

CertTemplate, PKIPublicationInfo, EncryptedKey, CertId,
  CertReqMessages, Controls, RegControlSet, id-regCtrl
FROM PKIXCRMF-2009
    { iso(1) identified-organization(3) dod(6) internet(1)
      security(5) mechanisms(5) pkix(7) id-mod(0)
      id-mod-crmf2005-02(55) }
    -- The import of EncryptedKey is added due to the updates made
    -- in [RFC9480]. EncryptedValue does not need to be imported
    -- anymore and is therefore removed here.

CertificationRequest
FROM PKCS-10
    {iso(1) identified-organization(3) dod(6) internet(1) security(5)
      mechanisms(5) pkix(7) id-mod(0) id-mod-pkcs10-2009(69)}
    -- (specified in [RFC2986] with 1993 ASN.1 syntax and IMPLICIT
    -- tags). Alternatively, implementers may directly include
    -- the syntax of [RFC2986] in this module.

localKeyId
FROM PKCS-9
    {iso(1) member-body(2) us(840) rsadsi(113549) pkcs(1) pkcs-9(9)
      modules(0) pkcs-9(1)}
    -- The import of localKeyId is added due to the updates made in
    -- [RFC9480]

EnvelopedData, SignedData
FROM CryptographicMessageSyntax-2010
    {iso(1) member-body(2) us(840) rsadsi(113549) pkcs(1) pkcs-9(9)
      smime(16) modules(0) id-mod-cms-2009(58)}
    -- The import of EnvelopedData and SignedData from [RFC6268] is
    -- added due to the updates made in CMP Updates [RFC9480]

KEM-ALGORITHM
FROM KEMAlgorithmInformation-2023 -- [RFC9629]
    { iso(1) identified-organization(3) dod(6) internet(1)
      security(5) mechanisms(5) pkix(7) id-mod(0)
      id-mod-kemAlgorithmInformation-2023(109) }
    -- The import of KEM-ALGORITHM was added due to the updates made
    -- in [RFC9810]
;

-- History of the PKIXCMP ASN.1 modules
-- [RFC2510]
--   1988 Syntax, PKIXCMP, 1.3.6.1.5.5.7.0.9 (id-mod-cmp)
--   Obsoleted by RFC 4210 PKIXCMP, 1.3.6.1.5.5.7.0.16
--                                     (id-mod-cmp2000)
-- [RFC4210]
--   1988 Syntax, PKIXCMP, 1.3.6.1.5.5.7.0.16 (id-mod-cmp2000)

```

```

-- Replaced by RFC 9480 PKIXCMP, 1.3.6.1.5.5.7.0.99
--                               (id-mod-cmp2021-88)
-- [RFC5912]
--   2002 Syntax, PKIXCMP-2009, 1.3.6.1.5.5.7.0.50
--                               (id-mod-cmp2000-02)
--   Replaced by RFC 9480 PKIXCMP-2021, 1.3.6.1.5.5.7.0.100
--                               (id-mod-cmp2021-02)
-- [RFC9480]
--   1988 Syntax, PKIXCMP, 1.3.6.1.5.5.7.0.99 (id-mod-cmp2021-88)
--   2002 Syntax, PKIXCMP-2021, 1.3.6.1.5.5.7.0.100
--                               (id-mod-cmp2021-02)
--   Obsoleted by [RFC9810] PKIXCMP-2023, 1.3.6.1.5.5.7.0.116
--                               (id-mod-cmp2023-02)
-- [RFC9810]
--   2002 Syntax, PKIXCMP-2023, 1.3.6.1.5.5.7.0.116
--                               (id-mod-cmp2023-02)

-- The rest of the module contains locally defined OIDs and
-- constructs:

CMPCertificate ::= CHOICE { x509v3PKCert Certificate, ... }
-- This syntax, while bits-on-the-wire compatible with the
-- standard X.509 definition of "Certificate", allows the
-- possibility of future certificate types (such as X.509
-- attribute certificates, card-verifiable certificates, or other
-- kinds of certificates) within this Certificate Management
-- Protocol, should a need ever arise to support such generality.
-- Those implementations that do not foresee a need to ever support
-- other certificate types MAY, if they wish, comment out the
-- above structure and "uncomment" the following one prior to
-- compiling this ASN.1 module. (Note that interoperability
-- with implementations that don't do this will be unaffected by
-- this change.)

-- CMPCertificate ::= Certificate

PKIMessage ::= SEQUENCE {
    header          PKIHeader,
    body            PKIBody,
    protection       [0] PKIProtection OPTIONAL,
    extraCerts       [1] SEQUENCE SIZE (1..MAX) OF CMPCertificate
                     OPTIONAL }

PKIMessages ::= SEQUENCE SIZE (1..MAX) OF PKIMessage

PKIHeader ::= SEQUENCE {
    pvno            INTEGER      { cmp1999(1), cmp2000(2),
                                cmp2021(3) },
    sender           GeneralName,
    -- identifies the sender
    recipient        GeneralName,
    -- identifies the intended recipient
    messageTime      [0] GeneralizedTime OPTIONAL,
    -- time of production of this message (used when sender
    -- believes that the transport will be "suitable", i.e.,
    -- that the time will still be meaningful upon receipt)
    protectionAlg     [1] AlgorithmIdentifier{ALGORITHM, {...}}

```

```

        OPTIONAL,
        -- algorithm used for calculation of protection bits
        senderKID      [2] KeyIdentifier      OPTIONAL,
        recipKID       [3] KeyIdentifier      OPTIONAL,
        -- to identify specific keys used for protection
        transactionID  [4] OCTET STRING      OPTIONAL,
        -- identifies the transaction, i.e., this will be the same in
        -- corresponding request, response, certConf, and pkiconf
        -- messages
        senderNonce    [5] OCTET STRING      OPTIONAL,
        recipNonce     [6] OCTET STRING      OPTIONAL,
        -- nonces used to provide replay protection, senderNonce
        -- is inserted by the creator of this message; recipNonce
        -- is a nonce previously inserted in a related message by
        -- the intended recipient of this message.
        freeText       [7] PKIFreeText       OPTIONAL,
        -- this may be used to indicate context-specific instructions
        -- (this field is intended for human consumption)
        generalInfo    [8] SEQUENCE SIZE (1..MAX) OF
                        InfoTypeAndValue    OPTIONAL
        -- this may be used to convey context-specific information
        -- (this field is not primarily intended for human consumption)
    }

    PKIFreeText ::= SEQUENCE SIZE (1..MAX) OF UTF8String
        -- text encoded as UTF-8 string [RFC3629]

    PKIBody ::= CHOICE {
        -- message-specific body elements
        ir      [0] CertReqMessages,      --Initialization Request
        ip      [1] CertRepMessage,       --Initialization Response
        cr      [2] CertReqMessages,      --Certification Request
        cp      [3] CertRepMessage,       --Certification Response
        p10cr   [4] CertificationRequest, --imported from [RFC2986]
        popdecc [5] POPDecKeyChallContent, --pop Challenge
        popdecr [6] POPDecKeyRespContent, --pop Response
        kur     [7] CertReqMessages,      --Key Update Request
        kup     [8] CertRepMessage,       --Key Update Response
        krr     [9] CertReqMessages,      --Key Recovery Request
        krp     [10] KeyRecRepContent,     --Key Recovery Response
        rr      [11] RevReqContent,       --Revocation Request
        rp      [12] RevRepContent,       --Revocation Response
        ccr     [13] CertReqMessages,     --Cross-Cert. Request
        ccp     [14] CertRepMessage,      --Cross-Cert. Response
        ckuann  [15] CAKeyUpdContent,     --CA Key Update Ann.
        cann    [16] CertAnnContent,     --Certificate Ann.
        rann    [17] RevAnnContent,      --Revocation Ann.
        crlann  [18] CRLAnnContent,      --CRL Announcement
        pkiconf [19] PKIConfirmContent,   --Confirmation
        nested  [20] NestedMessageContent, --Nested Message
        genm    [21] GenMsgContent,      --General Message
        genp    [22] GenRepContent,      --General Response
        error   [23] ErrorMsgContent,    --Error Message
        certConf [24] CertConfirmContent, --Certificate Confirm
        pollReq [25] PollReqContent,     --Polling Request
        pollRep [26] PollRepContent,     --Polling Response
    }

    PKIProtection ::= BIT STRING

```



```

ProtectedPart ::= SEQUENCE {
    header      PKIHeader,
    body        PKIBody }

id-PasswordBasedMac OBJECT IDENTIFIER ::= { iso(1) member-body(2)
    usa(840) nt(113533) nsn(7) algorithms(66) 13 }
PBMPParameter ::= SEQUENCE {
    salt          OCTET STRING,
    -- Note: Implementations MAY wish to limit acceptable sizes
    -- of this string to values appropriate for their environment
    -- in order to reduce the risk of denial-of-service attacks.
    owf           AlgorithmIdentifier{DIGEST-ALGORITHM, {...}},
    -- AlgId for the OWF
    iterationCount INTEGER,
    -- number of times the OWF is applied
    -- Note: Implementations MAY wish to limit acceptable sizes
    -- of this integer to values appropriate for their environment
    -- in order to reduce the risk of denial-of-service attacks.
    mac          AlgorithmIdentifier{MAC-ALGORITHM, {...}}
    -- AlgId of the MAC algorithm
}

id-DHBasedMac OBJECT IDENTIFIER ::= { iso(1) member-body(2)
    usa(840) nt(113533) nsn(7) algorithms(66) 30 }
DHBMParameter ::= SEQUENCE {
    owf           AlgorithmIdentifier{DIGEST-ALGORITHM, {...}},
    -- AlgId for an OWF
    mac          AlgorithmIdentifier{MAC-ALGORITHM, {...}}
    -- AlgId of the MAC algorithm
}

-- id-KemBasedMac and KemBMPParameter were added in [RFC9810]

id-KemBasedMac OBJECT IDENTIFIER ::= { iso(1) member-body(2)
    usa(840) nt(113533) nsn(7) algorithms(66) 16 }
KemBMPParameter ::= SEQUENCE {
    kdf           AlgorithmIdentifier{KEY-DERIVATION, {...}},
    -- AlgId of the Key Derivation Function algorithm
    kemContext    [0] OCTET STRING OPTIONAL,
    -- MAY contain additional algorithm-specific context information
    len           INTEGER (1..MAX),
    -- Defines the length of the keying material output of the KDF
    -- SHOULD be the maximum key length of the MAC function
    mac          AlgorithmIdentifier{MAC-ALGORITHM, {...}}
    -- AlgId of the MAC algorithm
}

PKIStatus ::= INTEGER {
    accepted      (0),
    -- you got exactly what you asked for
    grantedWithMods (1),
    -- you got something like what you asked for; the
    -- requester is responsible for ascertaining the differences
    rejection     (2),
    -- you don't get it, more information elsewhere in the message
    waiting       (3),
    -- the request body part has not yet been processed; expect to

```

```
-- hear more later (note: proper handling of this status
-- response MAY use the polling req/rep PKIMessages specified
-- in Section 5.3.22; alternatively, polling in the underlying
-- transport layer MAY have some utility in this regard)
revocationWarning      (4),
-- this message contains a warning that a revocation is
-- imminent
revocationNotification (5),
-- notification that a revocation has occurred
keyUpdateWarning       (6)
-- update already done for the oldCertId specified in
-- CertReqMsg
}

PKIFailureInfo ::= BIT STRING {
-- since we can fail in more than one way!
-- More codes may be added in the future if/when required.
  badAlg                (0),
  -- unrecognized or unsupported algorithm identifier
  badMessageCheck       (1),
  -- integrity check failed (e.g., signature did not verify)
  badRequest            (2),
  -- transaction not permitted or supported
  badTime               (3),
  -- messageTime was not sufficiently close to the system time,
  -- as defined by local policy
  badCertId             (4),
  -- no certificate could be found matching the provided criteria
  badDataFormat         (5),
  -- the data submitted has the wrong format
  wrongAuthority        (6),
  -- the authority indicated in the request is different from the
  -- one creating the response token
  incorrectData         (7),
  -- the requester's data is incorrect (for notary services)
  missingTimeStamp      (8),
  -- when the timestamp is missing but should be there
  -- (by policy)
  badPOP                (9),
  -- the POP failed
  certRevoked           (10),
  -- the certificate has already been revoked
  certConfirmed         (11),
  -- the certificate has already been confirmed
  wrongIntegrity        (12),
  -- KEM ciphertext missing for MAC-based protection of response,
  -- or not valid integrity of message received (password based
  -- instead of signature or vice versa)
  badRecipientNonce     (13),
  -- not valid recipient nonce, either missing or wrong value
  timeNotAvailable      (14),
  -- the TSA's time source is not available
  unacceptedPolicy      (15),
  -- the requested TSA policy is not supported by the TSA
  unacceptedExtension   (16),
  -- the requested extension is not supported by the TSA
  addInfoNotAvailable   (17),
  -- the additional information requested could not be
```

```

-- understood or is not available
badSenderNonce      (18),
-- not valid sender nonce, either missing or wrong size
badCertTemplate     (19),
-- not valid cert. template or missing mandatory information
signerNotTrusted    (20),
-- signer of the message unknown or not trusted
transactionIdInUse  (21),
-- the transaction identifier is already in use
unsupportedVersion   (22),
-- the version of the message is not supported
notAuthorized       (23),
-- the sender was not authorized to make the preceding
-- request or perform the preceding action
systemUnavail       (24),
-- the request cannot be handled due to system unavailability
systemFailure       (25),
-- the request cannot be handled due to system failure
duplicateCertReq    (26)
-- certificate cannot be issued because a duplicate
-- certificate already exists
}

PKIStatusInfo ::= SEQUENCE {
    status          PKIStatus,
    statusString    PKIFreeText      OPTIONAL,
    failInfo        PKIFailureInfo  OPTIONAL }

OOBCert ::= CMPCertificate

OOBCertHash ::= SEQUENCE {
    hashAlg         [0] AlgorithmIdentifier{DIGEST-ALGORITHM, {...}}
                      OPTIONAL,
    certId          [1] CertId          OPTIONAL,
    hashVal         BIT STRING
    -- hashVal is calculated over the DER encoding of the
    -- self-signed certificate with the identifier certID.
}

POPODecKeyChallContent ::= SEQUENCE OF Challenge
-- One Challenge per encryption or key agreement key certification
-- request (in the same order as these requests appear in
-- CertReqMessages).

-- encryptedRand was added in [RFC9810]

Challenge ::= SEQUENCE {
    owf              AlgorithmIdentifier{DIGEST-ALGORITHM, {...}}
                      OPTIONAL,
    -- MUST be present in the first Challenge; MAY be omitted in
    -- any subsequent Challenge in POPODecKeyChallContent (if
    -- omitted, then the owf used in the immediately preceding
    -- Challenge is to be used).
    witness          OCTET STRING,
    -- the result of applying the OWF to a
    -- randomly generated INTEGER, A. (Note that a different
    -- INTEGER MUST be used for each Challenge.)
    challenge        OCTET STRING,

```

```

-- MUST be used for cmp2000(2) popdecc messages and MUST be
-- the encryption of Rand (using a mechanism depending on the
-- private key type).
-- MUST be an empty OCTET STRING for cmp2021(3) popdecc messages.
-- Note: Using challenge omitting the optional encryptedRand is
-- bit-compatible to the syntax without adding this optional
-- field.
encryptedRand  [0] EnvelopedData OPTIONAL
-- MUST be omitted for cmp2000(2) popdecc messages.
-- MUST be used for cmp2021(3) popdecc messages and MUST contain
-- the encrypted value of Rand using CMS EnvelopedData using the
-- key management technique depending on the private key type as
-- defined in Section 5.2.2.
}

-- Rand was added in [RFC9480]

Rand ::= SEQUENCE {
-- Rand is encrypted involving the public key to form the content of
-- challenge or encryptedRand in POPODecKeyChallContent
  int          INTEGER,
-- the randomly generated INTEGER A (above)
  sender       GeneralName
-- the sender's name (as included in PKIHeader)
}

POPODecKeyRespContent ::= SEQUENCE OF INTEGER
-- One INTEGER per encryption or key agreement key certification
-- request (in the same order as these requests appear in
-- CertReqMessages). The retrieved INTEGER A (above) is returned to
-- the sender of the corresponding Challenge.

CertRepMessage ::= SEQUENCE {
  caPubs      [1] SEQUENCE SIZE (1..MAX) OF CMPCertificate
              OPTIONAL,
  response     SEQUENCE OF CertResponse }

CertResponse ::= SEQUENCE {
  certReqId    INTEGER,
-- to match this response with the corresponding request (a value
-- of -1 is to be used if certReqId is not specified in the
-- corresponding request, which can only be a p10cr)
  status       PKIStatusInfo,
  certifiedKeyPair CertifiedKeyPair OPTIONAL,
  rspInfo      OCTET STRING OPTIONAL
-- analogous to the id-regInfo-utf8Pairs string defined
-- for regInfo in CertReqMsg [RFC4211]
}

CertifiedKeyPair ::= SEQUENCE {
  certOrEncCert CertOrEncCert,
  privateKey     [0] EncryptedKey OPTIONAL,
-- See [RFC4211] for comments on encoding.
-- Changed from EncryptedValue to EncryptedKey as a CHOICE of
-- EncryptedValue and EnvelopedData due to the changes made in
-- [RFC9480].
-- Using the choice EncryptedValue is bit-compatible to the
-- syntax without this change.

```

```

    publicationInfo [1] PKIPublicationInfo OPTIONAL }

CertOrEncCert ::= CHOICE {
    certificate      [0] CMPCertificate,
    encryptedCert    [1] EncryptedKey
    -- Changed from Encrypted Value to EncryptedKey as a CHOICE of
    -- EncryptedValue and EnvelopedData due to the changes made in
    -- [RFC9480].
    -- Using the choice EncryptedValue is bit-compatible to the
    -- syntax without this change.
}

KeyRecRepContent ::= SEQUENCE {
    status            PKIStatusInfo,
    newSigCert        [0] CMPCertificate OPTIONAL,
    caCerts           [1] SEQUENCE SIZE (1..MAX) OF
                        CMPCertificate OPTIONAL,
    keyPairHist       [2] SEQUENCE SIZE (1..MAX) OF
                        CertifiedKeyPair OPTIONAL }

RevReqContent ::= SEQUENCE OF RevDetails

RevDetails ::= SEQUENCE {
    certDetails       CertTemplate,
    -- allows requester to specify as much as they can about
    -- the cert. for which revocation is requested
    -- (e.g., for cases in which serialNumber is not available)
    crlEntryDetails   Extensions{{...}} OPTIONAL
    -- requested crlEntryExtensions
}

RevRepContent ::= SEQUENCE {
    status            SEQUENCE SIZE (1..MAX) OF PKIStatusInfo,
    -- in same order as was sent in RevReqContent
    revCerts [0] SEQUENCE SIZE (1..MAX) OF CertId OPTIONAL,
    -- IDs for which revocation was requested
    -- (same order as status)
    crls             [1] SEQUENCE SIZE (1..MAX) OF CertificateList OPTIONAL
    -- the resulting CRLs (there may be more than one)
}

CAKeyUpdAnnContent ::= SEQUENCE {
    oldWithNew        CMPCertificate, -- old pub signed with new priv
    newWithOld         CMPCertificate, -- new pub signed with old priv
    newWithNew         CMPCertificate -- new pub signed with new priv
}

-- CAKeyUpdContent was added in [RFC9810]
CAKeyUpdContent ::= CHOICE {
    cAKeyUpdAnnV2      CAKeyUpdAnnContent, -- deprecated
    cAKeyUpdAnnV3 [0] RootCaKeyUpdateContent
}
-- With cmp2021, the use of CAKeyUpdAnnContent is deprecated, use
-- RootCaKeyUpdateContent instead.

CertAnnContent ::= CMPCertificate

RevAnnContent ::= SEQUENCE {

```

```

    status          PKIStatus,
    certId          CertId,
    willBeRevokedAt GeneralizedTime,
    badSinceDate    GeneralizedTime,
    crlDetails      Extensions{{...}} OPTIONAL
    -- extra CRL details (e.g., crl number, reason, location, etc.)
}

CRLAnnContent ::= SEQUENCE OF CertificateList

PKIConfirmContent ::= NULL

NestedMessageContent ::= PKIMessages

-- CertReqTemplateContent, AttributeTypeAndValue,
-- ExpandedRegControlSet, id-regCtrl-altCertTemplate,
-- AltCertTemplate, regCtrl-algId, id-regCtrl-algId, AlgIdCtrl,
-- regCtrl-rsaKeyLen, id-regCtrl-rsaKeyLen, and RsaKeyLenCtrl
-- were added in [RFC9480]

CertReqTemplateContent ::= SEQUENCE {
    certTemplate      CertTemplate,
    -- prefilled certTemplate structure elements
    -- The SubjectPublicKeyInfo field in the certTemplate MUST NOT
    -- be used.
    keySpec           Controls OPTIONAL
    -- MAY be used to specify supported algorithms
    -- Controls ::= SEQUENCE SIZE (1..MAX) OF AttributeTypeAndValue
    -- as specified in CRMF [RFC4211]
}

AttributeTypeAndValue ::= SingleAttribute({ ... })

ExpandedRegControlSet ATTRIBUTE ::= { RegControlSet |
    regCtrl-altCertTemplate | regCtrl-algId | regCtrl-rsaKeyLen, ... }

regCtrl-altCertTemplate ATTRIBUTE ::=
    { TYPE AltCertTemplate IDENTIFIED BY id-regCtrl-altCertTemplate }

id-regCtrl-altCertTemplate OBJECT IDENTIFIER ::= { id-regCtrl 7 }

AltCertTemplate ::= AttributeTypeAndValue
    -- specifies a template for a certificate other than an X.509v3
    -- public key certificate

regCtrl-algId ATTRIBUTE ::=
    { TYPE AlgIdCtrl IDENTIFIED BY id-regCtrl-algId }

id-regCtrl-algId OBJECT IDENTIFIER ::= { id-regCtrl 11 }

AlgIdCtrl ::= AlgorithmIdentifier{ALGORITHM, {...}}
    -- SHALL be used to specify supported algorithms other than RSA

regCtrl-rsaKeyLen ATTRIBUTE ::=
    { TYPE RsaKeyLenCtrl IDENTIFIED BY id-regCtrl-rsaKeyLen }

id-regCtrl-rsaKeyLen OBJECT IDENTIFIER ::= { id-regCtrl 12 }

```

```
RsaKeyLenCtrl ::= INTEGER (1..MAX)
-- SHALL be used to specify supported RSA key lengths

-- RootCaKeyUpdateContent, CRLSource, and CRLStatus were added in
-- [RFC9480]

RootCaKeyUpdateContent ::= SEQUENCE {
    newWithNew      CMPCertificate,
    -- new root CA certificate
    newWithOld      [0] CMPCertificate OPTIONAL,
    -- X.509 certificate containing the new public root CA key
    -- signed with the old private root CA key
    oldWithNew      [1] CMPCertificate OPTIONAL,
    -- X.509 certificate containing the old public root CA key
    -- signed with the new private root CA key
}

CRLSource ::= CHOICE {
    dpn             [0] DistributionPointName,
    issuer          [1] GeneralNames }

CRLStatus ::= SEQUENCE {
    source          CRLSource,
    thisUpdate      Time OPTIONAL }

-- KemCiphertextInfo and KemOtherInfo were added in [RFC9810]

KemCiphertextInfo ::= SEQUENCE {
    kem             AlgorithmIdentifier{KEM-ALGORITHM, {...}},
    -- AlgId of the KEM algorithm
    ct              OCTET STRING
    -- Ciphertext output from the Encapsulate function
}

KemOtherInfo ::= SEQUENCE {
    staticString     PKIFreeText,
    -- MUST be "CMP-KEM"
    transactionID    OCTET STRING,
    -- MUST contain the values from the message previously received
    -- containing the ciphertext (ct) in KemCiphertextInfo
    kemContext       [0] OCTET STRING OPTIONAL
    -- MAY contain additional algorithm-specific context information
}

INFO-TYPE-AND-VALUE ::= TYPE-IDENTIFIER

InfoTypeAndValue ::= SEQUENCE {
    infoType         INFO-TYPE-AND-VALUE.
                    &id({SupportedInfoSet}),
    infoValue        INFO-TYPE-AND-VALUE.
                    &Type({SupportedInfoSet}{@infoType}) }

SupportedInfoSet INFO-TYPE-AND-VALUE ::= { ... }

-- Example InfoTypeAndValue contents include, but are not limited
-- to, the following (uncomment in this ASN.1 module and use as
-- appropriate for a given environment):
--
```

```

-- id-it-caProtEncCert    OBJECT IDENTIFIER ::= {id-it 1}
--   CAProtEncCertValue   ::= CMPCertificate
-- id-it-signKeyPairTypes OBJECT IDENTIFIER ::= {id-it 2}
--   SignKeyPairTypesValue ::= SEQUENCE SIZE (1..MAX) OF
--                               AlgorithmIdentifier{...}}
-- id-it-encKeyPairTypes  OBJECT IDENTIFIER ::= {id-it 3}
--   EncKeyPairTypesValue  ::= SEQUENCE SIZE (1..MAX) OF
--                               AlgorithmIdentifier{...}}
-- id-it-preferredSymmAlg OBJECT IDENTIFIER ::= {id-it 4}
--   PreferredSymmAlgValue  ::= AlgorithmIdentifier{...}}
-- id-it-caKeyUpdateInfo  OBJECT IDENTIFIER ::= {id-it 5}
--   CAKeyUpdateInfoValue  ::= CAKeyUpdAnnContent
--   - id-it-caKeyUpdateInfo was deprecated with cmp2021
-- id-it-currentCRL       OBJECT IDENTIFIER ::= {id-it 6}
--   CurrentCRLValue      ::= CertificateList
-- id-it-unsupportedOIDs  OBJECT IDENTIFIER ::= {id-it 7}
--   UnsupportedOIDsValue  ::= SEQUENCE SIZE (1..MAX) OF
--                               OBJECT IDENTIFIER
-- id-it-keyPairParamReq  OBJECT IDENTIFIER ::= {id-it 10}
--   KeyPairParamReqValue  ::= OBJECT IDENTIFIER
-- id-it-keyPairParamRep  OBJECT IDENTIFIER ::= {id-it 11}
--   KeyPairParamRepValue  ::= AlgorithmIdentifier{...}}
-- id-it-revPassphrase    OBJECT IDENTIFIER ::= {id-it 12}
--   RevPassphraseValue    ::= EncryptedKey
--   - Changed from Encrypted Value to EncryptedKey as a CHOICE
--   - of EncryptedValue and EnvelopedData due to the changes
--   - made in [RFC9480]
--   - Using the choice EncryptedValue is bit-compatible to
--   - the syntax without this change
-- id-it-implicitConfirm  OBJECT IDENTIFIER ::= {id-it 13}
--   ImplicitConfirmValue  ::= NULL
-- id-it-confirmWaitTime  OBJECT IDENTIFIER ::= {id-it 14}
--   ConfirmWaitTimeValue  ::= GeneralizedTime
-- id-it-origPKIMessage   OBJECT IDENTIFIER ::= {id-it 15}
--   OrigPKIMessageValue   ::= PKIMessages
-- id-it-supplLangTags    OBJECT IDENTIFIER ::= {id-it 16}
--   SupplLangTagsValue    ::= SEQUENCE OF UTF8String
-- id-it-caCerts          OBJECT IDENTIFIER ::= {id-it 17}
--   CaCertsValue          ::= SEQUENCE SIZE (1..MAX) OF
--                               CMPCertificate
--   - id-it-caCerts added in [RFC9480]
-- id-it-rootCaKeyUpdate  OBJECT IDENTIFIER ::= {id-it 18}
--   RootCaKeyUpdateValue  ::= RootCaKeyUpdateContent
--   - id-it-rootCaKeyUpdate added in [RFC9480]
-- id-it-certReqTemplate  OBJECT IDENTIFIER ::= {id-it 19}
--   CertReqTemplateValue  ::= CertReqTemplateContent
--   - id-it-certReqTemplate added in [RFC9480]
-- id-it-rootCaCert       OBJECT IDENTIFIER ::= {id-it 20}
--   RootCaCertValue       ::= CMPCertificate
--   - id-it-rootCaCert added in [RFC9480]
-- id-it-certProfile      OBJECT IDENTIFIER ::= {id-it 21}
--   CertProfileValue      ::= SEQUENCE SIZE (1..MAX) OF
--                               UTF8String
--   - id-it-certProfile added in [RFC9480]
-- id-it-crlStatusList    OBJECT IDENTIFIER ::= {id-it 22}
--   CRLStatusListValue    ::= SEQUENCE SIZE (1..MAX) OF
--                               CRLStatus
--   - id-it-crlStatusList added in [RFC9480]

```



```

-- id-it-crls          OBJECT IDENTIFIER ::= {id-it 23}
--   CRLsValue         ::= SEQUENCE SIZE (1..MAX) OF
--                               CertificateList
--   - id-it-crls added in [RFC9480]
-- id-it-KemCiphertextInfo OBJECT IDENTIFIER ::= {id-it 24}
--   KemCiphertextInfoValue ::= KemCiphertextInfo
--   - id-it-KemCiphertextInfo was added in [RFC9810]
--
-- where
--
--   id-pkix OBJECT IDENTIFIER ::= {
--     iso(1) identified-organization(3)
--     dod(6) internet(1) security(5) mechanisms(5) pkix(7)}
-- and
--   id-it OBJECT IDENTIFIER ::= {id-pkix 4}
--
-- This construct MAY also be used to define new PKIX Certificate
-- Management Protocol request and response messages or
-- general-purpose (e.g., announcement) messages for future needs
-- or for specific environments.

```

GenMsgContent ::= SEQUENCE OF InfoTypeAndValue

```

-- May be sent by EE, RA, or CA (depending on message content).
-- The OPTIONAL infoValue parameter of InfoTypeAndValue will
-- typically be omitted for some of the examples given above.
-- The receiver is free to ignore any contained OIDs that it
-- does not recognize. If sent from EE to CA, the empty set
-- indicates that the CA may send
-- any/all information that it wishes.

```

GenRepContent ::= SEQUENCE OF InfoTypeAndValue

```

-- The receiver MAY ignore any contained OIDs that it does not
-- recognize.

```

```

ErrorMsgContent ::= SEQUENCE {
  pkiStatusInfo      PKIStatusInfo,
  errorCode          INTEGER          OPTIONAL,
  -- implementation-specific error codes
  errorDetails       PKIFreeText     OPTIONAL
  -- implementation-specific error details
}

```

CertConfirmContent ::= SEQUENCE OF CertStatus

```

CertStatus ::= SEQUENCE {
  certHash    OCTET STRING,
  -- the hash of the certificate, using the same hash algorithm
  -- as is used to create and verify the certificate signature
  certReqId   INTEGER,
  -- to match this confirmation with the corresponding req/rep
  statusInfo  PKIStatusInfo OPTIONAL,
  hashAlg [0] AlgorithmIdentifier{DIGEST-ALGORITHM, {...}} OPTIONAL
  -- the hash algorithm to use for calculating certHash
  -- SHOULD NOT be used in all cases where the AlgorithmIdentifier
  -- of the certificate signature specifies a hash algorithm
}

```

```
PollReqContent ::= SEQUENCE OF SEQUENCE {
    certReqId          INTEGER }

PollRepContent ::= SEQUENCE OF SEQUENCE {
    certReqId          INTEGER,
    checkAfter         INTEGER, -- time in seconds
    reason             PKIFreeText OPTIONAL }

--
-- ECU extension for PKI entities used in CMP
-- operations, added due to the changes made in [RFC9480]
-- The EKUs for the CA and RA are reused from CMC, as defined in
-- [RFC6402]
--

-- id-kp-cmcCA OBJECT IDENTIFIER ::= { id-kp 27 }
-- id-kp-cmcRA OBJECT IDENTIFIER ::= { id-kp 28 }
id-kp-cmKGA OBJECT IDENTIFIER ::= { id-kp 32 }

END
```

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Authors' Addresses

Hendrik Brockhaus

Siemens
Werner-von-Siemens-Strasse 1
80333 Munich
Germany
Email: hendrik.brockhaus@siemens.com
URI: <https://www.siemens.com>

David von Oheimb

Siemens
Werner-von-Siemens-Strasse 1
80333 Munich
Germany
Email: david.von.oheimb@siemens.com
URI: <https://www.siemens.com>

Mike Ounsworth

Entrust

1187 Park Place

Minneapolis, MN 55379

United States of America

Email: mike.ounsworth@entrust.comURI: <https://www.entrust.com>**John Gray**

Entrust

1187 Park Place

Minneapolis, MN 55379

United States of America

Email: john.gray@entrust.comURI: <https://www.entrust.com>