Generic CMP client library API

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Table of Contents

PUBLIC....1

1. INTRODUCTION....3

1.1 Motivation and Purpose....3
1.2 Scope and Status....3
1.3 References....4

2. OVERVIEW....4

3. CORE FUNCTIONALITY....6

3.1 CMPclient_prepare....6
3.2 CMPclient_setup_HTTP and CMPclient_setup_BIO....8
3.3 CMPclient_add_certProfile....10
3.4 CMPclient_imprint, CMPclient_bootstrap, CMPclient_pkcs10, CMPclient_update, and CMPclient_update_anycert....10
3.5 CMPclient_revoke....12
3.6 CMPclient_caCerts....12
3.7 CMPclient_certReqTemplate....12
3.8 CMPclient_rootCaCert....12
3.9 CMPclient_crlUpdate....13
3.10 CMPclient_snprint_PKIStatus....13
3.11 CMPclient_reinit....13
3.12 CMPclient_finish....13
3.13 Logging....14
3.14 Message transfer callback function....15
3.15 Certificate checking callback function....15
3.16 Component credentials....16

4. SUPPORT FUNCTIONALITY....17

4.1 CREDENTIALS helpers....17
4.2 X509_STORE helpers....18
4.3 EVP_PKEY helpers....21
4.4 SSL_CTX helpers....21
4.5 X509_EXTENSIONS helpers....22

5. APPENDIX: C HEADER FILE....23

1. Introduction

1.1 Motivation and Purpose

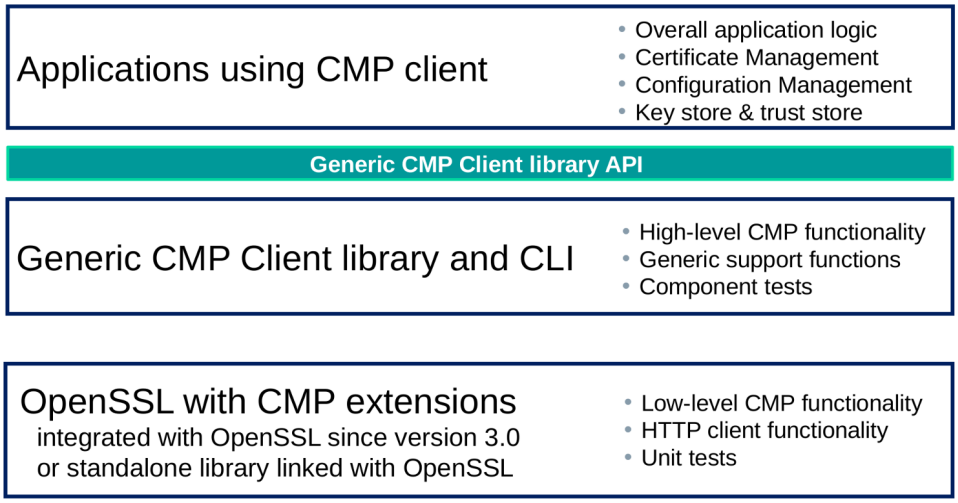
CMP ([RFC9810], originally [RFC4210]), including CRMF ([RFC4211] updated by [RFC9045]) and HTTP transfer for CMP ([RFC9811], originally [RFC6712]), is a certificate management protocol, supporting the enrollment, update, and revocation of certificates.

In late 2024, IETF released updates to CMP [RFC 9480] as well as a Lightweight CMP Profile [LCMPP, RFC 9483] for industrial and IoT application scenarios. These provided extensions to CMPv2 supporting specific message exchanges for retrieving CA certificates, root CA certificate updates, certificate request templates, and CRLs, as well as support for certificate profiles, central key generation, and polling for all types of CMP responses. These features are also covered here.

This document describes the Application Programming Interface (API) for the development of a generic CMP client library.

1.2 Scope and Status

There is an open-source CMP client implementation that we build upon: CMPforOpenSSL, located on GitHub [cmpossl]. It offers both a library based on OpenSSL with a low-level C API and a high-level command-line interface (CLI).



Goal when designing this interface was to offer a medium-level API based on the low-level CMPforOpenSSL API that on the one hand is convenient to use for application programmers and on the other hand is complete and flexible enough to cover the major certificate management use cases. Besides its generic character, the library supports developing specific CMP clients that fulfill the Lightweight CMP Profile for Industrial Certificate Management Use Cases [LCMPP].

The implementation makes use of the SecurityUtilities library [libsecutils]. It also uses either the CMP implementation integrated with OpenSSL since version 3.0 or CMPforOpenSSL, a standalone intermediate CMP library with the latest features and fixes, which can by dynamically linked to OpenSSL 3.0 or later. For details, history, and more current information please refer to the Wiki page of [cmpossl].

The library has been open-sourced by Siemens AG as version 1.0 on 17th September 2021.

On top of the API a rather extensive CMP client CLI is available as demo application and for testing and exploration purposes.

Instructions for obtaining, building, installing, and using the library and the CLI can be found at [genCMPClient].

1.3 References

Reference ID	Document with title, unique identifier and version
[RFC4210]	RFC4210: “Internet X.509 Public Key Infrastructure -- Certificate Management Protocol (CMP)“, 2005 https://www.rfc-editor.org/info/rfc4210
[RFC4211]	RFC4211: “Internet X.509 Public Key Infrastructure -- Certificate Request Message Format (CRMF)”, 2005 https://www.rfc-editor.org/info/rfc4211
[RFC5280]	RFC5280: “Certificate and Certificate Revocation List (CRL) Profile”, 2008 https://www.rfc-editor.org/info/rfc5280
[RFC6712]	RFC6712: “Internet X.509 Public Key Infrastructure -- HTTP Transfer for the Certificate Management Protocol (CMP)”, 2012 https://www.rfc-editor.org/info/rfc6712
[RFC9045]	Algorithm Requirements Update to the Internet X.509 Public Key Infrastructure -- Certificate Request Message Format (CRMF), 2021 https://www.rfc-editor.org/info/rfc9045
[RFC9810]	RFC9810: “Internet X.509 Public Key Infrastructure -- Certificate Management Protocol (CMP)“, 2025 https://www.rfc-editor.org/info/rfc9810
[RFC9811]	RFC9811: “Internet X.509 Public Key Infrastructure -- HTTP Transfer for the Certificate Management Protocol (CMP)”, 2025 https://www.rfc-editor.org/info/rfc9811
[OID-ref]	OID database, reference record for OID 1.3.6.1.5.5.7.3, 2019 http://oidref.com/1.3.6.1.5.5.7.3
[OpenSSL-ciphers]	OpenSSL manual page on SSL/TLS ciphers, 2019 https://www.openssl.org/docs/manmaster/man1/ciphers.html
[OpenSSL-ext-config]	OpenSSL manual page on X509 V3 certificate extension config format, 2019 https://www.openssl.org/docs/manmaster/man5/x509v3_config.html
[OpenSSl-provider]	OpenSSL manual page on the crypto provider API, 2022 https://github.com/openssl/openssl/blob/master/README-PROVIDERS.md
[OpenSSL-engine]	OpenSSL manual page on the crypto engine API, 2019 https://github.com/openssl/openssl/blob/master/README-ENGINES.md https://www.openssl.org/docs/manmaster/man3/ENGINE_init.html
[OpenSSL-sec-level]	OpenSSL manual page on SSL/TLS security level, 2019 https://www.openssl.org/docs/manmaster/man3/SSL_CTX_get_security_level.html
[cmpossl]	M. Peylo and D. von Oheimb: CMP for OpenSSL project, 2019 https://github.com/mpeylo/cmpossl (code repository including documentation)
[libsecutils]	D. von Oheimb et al.: Security Utilities library, 2019 https://github.com/siemens/libsecutils
[genCMPClient]	D. von Oheimb: Generic CMP Client library and CLI, 2023 http://github.com/siemens/genCMPClient
[LCMPP, RFC9483]	IETF RFC 9483 – H. Brockhaus, S. Fries, and D. von Oheimb: “Lightweight Certificate Management Protocol (CMP) Profile”, 2024 https://www.rfc-editor.org/info/rfc9483

2. Overview

This CMP client library is built on top of CMPforOpenSSL, which in turn was originally built on top of OpenSSL 1.x and then has been integrated with OpenSSL 3.0. Thus we inherit several declarations from there. In particular, the type `CMP_CTX` defining the context data structure for the low-level CMPforOpenSSL client library functions that will be re-used in the medium-level API.

For best usability and flexibility, we condense the CMP client core functionality into a few rather high-level functions that allow setting all typically required use case parameters. Each CMP use case can be executed by calling several of these functions to form a CMP client transaction as described next – see also the example code at the end of this section.

In order to enable the use of the low-level CMPforOpenSSL functions we directly re-use their CMP context data structure (of type `CMP_CTX`). This context includes all parameters and state information of a CMP transaction. The function `CMPclient_prepare()` sets up those parts of the context data structure generally needed for all use cases. As far as needed, the pointer provided by this function (typically named `ctx`) may be used to set up any further, uncommon CMP client parameters. In this way we make sure that the low-level API of OpenSSL or CMPforOpenSSL defined in the C header file `cmp.h` can be used jointly with this API.

One of the parameters of `CMPclient_prepare()` is the callback function pointer `transfer_fn`. By default (when `NULL` is given as the actual argument), standard HTTP(S) transfer is selected. In this case, a second function, `CMPclient_setup_HTTP()` or `CMPclient_setup_BIO()`, must be called next in order to provide the required HTTP parameters such as the server host and HTTP path. Note that as CMP messages are self-contained, any transfer (including offline one) is supported. This implementation supports an overall timeout per CMP transaction, where the default HTTP transfer supports a timeout per message exchange. Polling for requested certificates, as defined by [RFC9810], as well as delayed delivery for all types of responses as defined in [LCMPP], is done automatically when needed.

Then the actual activity for the given use case is invoked, by calling an enrollment function (`CMPclient_imprint()`, `CMPclient_bootstrap()`, `CMPclient_pkcs10()`, `CMPclient_update()`, `CMPclient_update_anycert()`), `CMPclient_revoke()`, or one of the special information retrieval functions (`CMPclient_caCerts()`, `CMPclient_rootCaCert()`, `CMPclient_certReqTemplate()`, `CMPclient_crlUpdate()`), with their use-case-specific arguments.

`CMPclient_snprint_PKIStatus()` may then be called to vet detailed status or error information provided by the server.
The CMP context may be reused for further such activities after calling `CMPclient_reinit()`.

Finally the transaction must be closed by calling `CMPclient_finish()`, which deallocates all internal resources in the given CMP context.

Thus, at the given level of abstraction, a typical invocation sequence would look like this:

```
CMPErr err = CMPclient_init("my CMP client", log_fn);
CMP_CTX *ctx = NULL;
…
err = CMPclient_prepare(&ctx, log_fn,
                        cmp_truststore, recipient, untrusted,
                        creds, creds_truststore, digest, mac,
                        transfer_fn, total_timeout,
                        new_cert_truststore, implicit_confirm);
…
err = CMPclient_setup_HTTP(ctx, server, path, timeout, tls, proxy, no_proxy);
…
err = CMPclient_imprint(ctx, &new_creds, new_key, subject, exts);
if (CMPclient_snprint_PKIStatus(ctx, buf, bufsize) != NULL)
    LOG(FL_INFO, buf);
…
err = CMPclient_reinit(ctx);
```

```
…
err = CMPclient_bootstrap(ctx, &new_creds2, new_key2, subject2, exts2);
…
CMPclient_finish(ctx); /* this also deallocates ctx */
```

The various parameters, as well as the meaning and the results of these functions are described in the next section.

Any number of transactions may be executed in a row or even in parallel as long as each of them uses its own CMP context pointer obtained by calling **`CMPclient_prepare()`**.

The actual C header file with all relevant declarations can be found in the appendix.

The coding style of the library is compatible with the C90 standard.

3. Core functionality

This section describes the essential functions of the generic CMP client library. These functions give feedback to the caller on their success or failure and the reason for any failure. We define the return type `CMP_err` more abstractly than currently in the header file `cmp.h` of CMPforOpenSSL while the idea is the same: `CMP_OK` = `0` (zero) means no error, else the code indicates the failure reason. The various error codes are defined in `<openssl/cmperr.h>`.

The function `CMPclient_init()` initializes the underlying OpenSSL library, and optionally sets up a module name, defaulting to `"genCMPClient"`, used for logging as well as a log callback function as described in section 3.13 for use by the SecurityUtilities library. It should be called once, as soon as the overall application starts. If the `log_fn` argument is `NULL` the library uses `LOG_default()` both using the syslog facility and printing to the console.

```
CMP_err CMPclient_init(OPTIONAL const char *name, OPTIONAL LOG_cb_t log_fn);
```

3.1 CMPclient_prepare

The function `CMPclient_prepare()` allocates the internal CMP context data structure (of type `CMP_CTX`) and set up those CMP parameters common to all use cases. On success, it assigns the pointer to the structure via the address of a variable that must be supplied as the first parameter. Note that this function, as well as the following ones, internally modify the CMP context and therefore this context is not declared `const`.

Param.	Type	Name	Meaning
	`CMP_CTX **`	`pctx`	Pointer to the variable that will obtain the context
`OPTIONAL`	`OSSL_LIB_CTX *`	`libctx`	Optional pointer to an OpenSSL library context, which may be used for non-default crypto providers
`OPTIONAL`	`const char *`	`propq`	Optional property query for crypto algorithm selection
`OPTIONAL`	`LOG_cb_t`	`log_fn`	Function to be called for logging CMP related errors, warnings, etc. If `NULL` is given, `LOG_default()` is used. See section 3.13 for details.
`OPTIONAL`	`X509_STORE *`	`cmp_truststore`	Trust store for authenticating the CMP server. For efficiency this data structure is not copied but its reference counter is incremented on success. Although it might get modified, it may be reused. The argument may be `NULL` in case symmetric mutual authentication is done (via `creds`).
`OPTIONAL`	`const char *`	`recipient`	X.509 Distinguished Name in the form `"/<type0>=<value0>/<type1>=<value1>..."` to use for the recipient field of CMP headers. If `NULL` then information from the `creds` or `untrusted` parameter or the NULL DN is taken as fallback.
`OPTIONAL`	`const STACK_OF (X509) *`	`untrusted`	Non-trusted intermediate CA certificates that may be useful for path construction when authenticating the server (i.e., the signer of received CMP response messages) and for verifying newly enrolled certificates. If `NULL` then any chain included in the `creds` parameter is taken as fallback. If the `recipient` argument is `NULL` and

			the `creds` argument is `NULL` or does not contain a client certificate the recipient of CMP messages sent is taken from the subject of the first certificate in this list, if any.
OPTIONAL	`const CREDENTIALS *`	`creds`	CMP client key material for protecting requests and authenticating to the server, or `NULL` in case requests should not be protected. Any password (symmetric key) included may also be used in opposite direction. See section 3.16 for details. If a client certificate is included its subject is taken as the sender and, unless the `recipient` argument is given, its issuer is taken as fallback value for the recipient field of CMP messages. If a certificate chain is included it is appended to the list of `untrusted` certificates.
OPTIONAL	`X509_STORE *`	`creds_ truststore`	If this trust store is provided it is used to verify the chain building for the own CMP signer certificate. Otherwise an approximate chain is built as far as possible, ignoring errors. In both cases the `untrusted` certificates (with any `creds->chain` appended to them) are used for certificate path construction.
OPTIONAL	`const char *`	`digest`	Name of hash function to use as one-way function (OWF) in PBM-based message protection and as digest algorithm for signature-based message protection and proof-of-possession (POPO) . The default is `"sha256"`. The available digest names can be shown with the command `openssl list -digest-commands`
OPTIONAL	`const char *`	`mac`	Name of MAC algorithm to use in RFC 9810's MSG_MAC_ALG for PBM-based message protection. The default is `"hmac-sha1"` as per RFC 4210.
OPTIONAL	`OSSL_CMP_transfer_cb_t`	`transfer_fn`	Function to be called for message transfer. See section 3.14 for details.
	`int`	`total_ timeout`	Maximum total time (in seconds) a CMP transaction (including any certificate conformation and polling) may take, or <= `0` for infinite, which is the default
OPTIONAL	`X509_STORE *`	`new_cert_ truststore`	Trust store to be used for verifying the newly enrolled certificate. See section 3.15 for details. For efficiency this data structure is not copied but its reference counter is incremented on success. Although it might get modified, it may be reused.
	`bool`	`implicit_ confirm`	Flag whether to request implicit confirmation for enrolled certificates

Example use (for the parts replaced by '…', see sections 4.2 and 4.1):

```
CMP_err err;
CMP_CTX *ctx = NULL;
LOG_cb_t log_fn = NULL;
X509_STORE *cmp_truststore = …
const X509_char_*recipient = NULL;
const STACK_OF(X509) *untrusted = …
CREDENTIALS *creds = …
X509_STORE *creds_truststore = …
const char *digest = "sha256";
const char *mac = NULL;
OSSL_CMP_transfer_cb_t transfer_fn = NULL; /* default HTTP(S) transfer */
int total_timeout = 100;
X509_STORE *new_cert_truststore = …
bool implicit_confirm = false;
err = CMPclient_prepare(&ctx, log_fn,
                        cmp_truststore, recipient,
                        untrusted, creds, creds_truststore, digest, mac,
                        transfer_fn, total_timeout,
                        new_cert_truststore, implicit_confirm);
```

3.2 CMPclient_setup_HTTP and CMPclient_setup_BIO

The function `CMPclient_setup_HTTP()` sets up in the given CMP context the parameters relevant for HTTP transfer. As mentioned in section 2, this is needed if HTTP(S) is used. All string parameters are copied and so may be deallocated immediately. The optional `tls` parameter is not copied but its reference counter is increased, so modifications may be shared; it may also be deallocated anytime.

Param.	Type	Name	Meaning
	`CMP_CTX *`	`ctx`	CMP context to modify
	`const char *`	`server`	Server URI, of the form `"[http[s]://]<host>[:<port>][/path]"`, with the default port being 80. An IPv6 address must be enclosed in '[' and ']'. Any given path is overridden by `path` if provided.
`OPTIONAL`	`const char *`	`path`	Server HTTP path (aka CMP alias) with the default taken from the `server` argument, else "`/`".
	`int`	`keep_alive`	If 0 then HTTP connections are closed after each response, which is the default for HTTP 1.0. If 1 or 2 is given then persistent connections within a transaction are requested. On 2 they are required, i.e., in case the server does not grant them an error occurs. A negative value assumes 1, which is the default for HTTP 1.1 and means preferring to keep the connection open.
	`int`	`timeout`	Maximum time (in seconds) a single response to an HTTP POST request may take, or 0 for infinite, or `< 0` for default, which is 120 seconds.
`OPTIONAL`	`SSL_CTX *`	`tls`	The TLS parameters if TLS shall be used, else `NULL`. For efficiency, this data structure is not copied but its reference counter is incremented on success.

			Although it might get modified, it may be reused. On TLS client connection setup some extra preparation steps are performed: If the `server` **<host>** part is not `localhost`, `127.0.0.1`, or `::1` and `tls` contains a trust store that does not already include any hostname, IP address, or email address validation information, the hostname part of the server is set there using **`STORE_set1_host_ip()`**. The first hostname set in the trust store if available, otherwise the <host> part of the `server` (unless it is an IP address), is used to set up Server Name Indication (SNI, RFC 3546 section 3.1).
OPTIONAL	**`const char *`**	`proxy`	HTTP(S) proxy address, of the form **`"[http[s]://]<host>[:<port>][/path]"`**, with the default port being 80. Its default is the environment variable **`http_proxy`** or **`https_proxy`**, respectively. Any included http(s) prefix and path are ignored. No proxy is used if the server host matches the `no_proxy` setting.
OPTIONAL	**`const char *`**	`no_proxy`	List of server hosts not use an HTTP(S) proxy for, separated by commas and/or whitespace. Default is the environment variable **`no_proxy`**.

Example use (for the parts replaced by '…' and `TLS_new()`, see section 4.4):

```
const char *server = "my.cmp-server.com:443";
const char *path = "/pkix";
const char *proxy = NULL;
const char *no_proxy = NULL;
int keep_alive = -1;
int timeout = 10;
X509_STORE *tls_truststore = …
const STACK_OF(X509) *tls_untrusted = NULL;
CREDENTIALS *tls_creds = …
char *ciphers = NULL; /* or, e.g., "HIGH:!ADH:!LOW:!EXP:!MD5:@STRENGTH" */
SSL_CTX *tls = TLS_new(tls_truststore, tls_untrusted,
                       tls_creds, ciphers, -1);
err = CMPclient_setup_HTTP(ctx, server, path, keep_alive, timeout, tls,
                           proxy, no_proxy);
```

The function **`CMPclient_setup_BIO()`** is a more basic alternative to **`CMPclient_setup_HTTP()`** for the case that an already opened connection (e.g., SSL/TLS) shall be used for HTTP transfer.

Param.	Type	Name	Meaning
	`CMP_CTX *`	`ctx`	CMP context to modify
	`BIO *`	`rw`	Read-write BIO to use. It will not be closed by the library after a transaction.
OPTIONAL	**`const char *`**	`path`	Server HTTP path (aka CMP alias) with the default taken from the `server` argument, else "/".

	int	keep_alive	If 0 then HTTP connections are not requested to be kept alive, which is the default for HTTP 1.0. If 1 or 2 is given then persistent connections are requested. On 2 they are required, i.e., in case the server does not grant them an error occurs. A negative value assumes 1, which is the default for HTTP 1.1 and means preferring to keep the connection open.
	int	timeout	Maximum time (in seconds) a single response to an HTTP POST request may take, or 0 for infinite, or < 0 for default, which is 120 seconds.

3.3 CMPclient_add_certProfile

The function CMPclient_add_certProfile() may be used to specify a certificate profile name to be added to CMP headers. In case a NULL pointer is given, OSSL_CMP_CTX_reset_geninfo_ITAVs() is called, which removes any previously given names.

Param.	Type	Name	Meaning
	CMP_CTX *	ctx	CMP context to modify
OPTIONAL	const char *	path	Profile name to add, which may be UTF8-encoded

3.4 CMPclient_imprint, CMPclient_bootstrap, CMPclient_pkcs10, CMPclient_update, CMPclient_update_anycert, CMPclient_update_with_exts

The functions CMPclient_imprint() and CMPclient_bootstrap() request a certificate, either an initial one (using the CMP type 'ir', see [LCMPP section 4.1.1], e.g., as part of imprinting the IDevID during manufacturing or when a BRSKI-AE pledge requests the device-wide LDevID-generic certificate from the device operator) or a regular one (using 'cr', see [LCMPP section 4.1.2], e.g., when requesting application-specific LDevIDs from the operator).

Param.	Type	Name	Meaning
	CMP_CTX *	ctx	CMP context to use
	CREDENTIALS **	new_creds	Pointer to variable to obtain the enrolled cert etc. With central key generation, this includes the private key obtained from the server.
	const EVP_PKEY *	new_key	Private key for the new certificate. If central key generation is requested, only the key type (i.e., its algorithm and size info) is used. Otherwise the private key is used for signature-based POPO and the corresponding public key is placed in the certTemplate of the request. Note that an EVP_PKEY structure can be used also for HW-based keys. In this case it does not include the key material itself but a reference to key material via a crypto provider or legacy crypto engine.
	const char *	subject	X.509 Subject Distinguished Name (DN) in the form "/<type0>=<value0>/<type1>=<value1>...". If the creds argument of is NULL or does not contain

			a certificate this name is taken as the sender field of the CMP messages sent.
OPTIONAL	const X509_EXTENSIONS *	exts	X.509v3 extensions to place in the certTemplate

The function CMPclient_pkcs10() performs certificate enrollment based on a legacy PKCS#10 CSR (if CRMF cannot be used) using the CMP command 'p10cr', see [LCMPP section 4.1.4].

Param.	Type	Name	Meaning
	CMP_CTX *	ctx	CMP context to use
	CREDENTIALS **	new_creds	Pointer to variable to obtain the enrolled cert etc.
	const X509_REQ *	pc10csr	Legacy PKCS#10 certificate signing request to use

The function CMPclient_update() performs a certificate update, aka re-enrollment using the CMP command 'kur', see [LCMPP section 4.1.3]. The certificate to be updated is the cert component of the creds argument given to CMPclient_prepare(). The subject, any subject alternative names, and also any further X.509v3 extensions (except for subject key identifier and authority key identifier) in the certificate to be updated are taken over in the request certTemplate. If the new_key parameter is NULL, it defaults to the key component of the creds argument given to CMPclient_prepare().

Param.	Type	Name	Meaning
	CMP_CTX *	ctx	CMP context to use
	CREDENTIALS **	new_creds	Pointer to variable to obtain the enrolled cert etc.
OPTIONAL	const EVP_PKEY *	new_key	Key (pair), as described for CMPclient_bootstrap()

The function CMPclient_update_anycert() is a generalization of CMPclient_update() where the certificate to be updated can be given as the old_cert parameter. If old_cert is NULL the function behaves like CMPclient_update().

Param.	Type	Name	Meaning
	CMP_CTX *	ctx	CMP context to use
	CREDENTIALS **	new_creds	Pointer to variable to obtain the enrolled cert etc.
OPTIONAL	const X509 *	old_cert	Certificate to be updated
OPTIONAL	const EVP_PKEY *	new_key	Key (pair); see above description in section 3.4

The function CMPclient_update_with_exts() is also a generalization of CMPclient_update() where the certificate to be updated can be given as the old_cert parameter, yet here by default only any subject alternative names are taken from the certificate, while further X.509v3 extensions are taken from the optional exts parameter rather than from the certificate to be updated.

Param.	Type	Name	Meaning
	CMP_CTX *	ctx	CMP context to use
	CREDENTIALS **	new_creds	Pointer to variable to obtain the enrolled cert etc.
OPTIONAL	const X509 *	old_cert	Certificate to be updated
OPTIONAL	const EVP_PKEY *	new_key	Key (pair); see above description in section 3.4

OPTIONAL	const X509_EXTENSIONS *	exts	X.509v3 extensions to place in the certTemplate

The requests may refer to a certificate profile set before using `CMPclient_add_certProfile()`. For requesting central key generation,

```
OSSL_CMP_CTX_set_option(ctx, OSSL_CMP_OPT_POPO_METHOD, OSSL_CRMF_POPO_NONE)
```

must be called before.

Any certificate confirmation and polling for responses is handled under the hood. This implies that the call will block until a final response is received or a timeout has occurred.

On success, each of the enrollment functions allocates a `CREDENTIALS` structure and fills it with the `new_key` argument supplied (or `NULL` in case of `CMPclient_pkcs10()`), the newly enrolled certificate, and a chain for this certificate. The chain is constructed from the list of untrusted certificates held in the CMP context, which includes any certificates provided by the server in the `extraCerts` field of responses. The pointer to the structure is returned via the pointer to a variable supplied as the `new_creds` parameter.

Example use (for `KEY_new()`, see section 4.3, for the part replaced by '…', see section 4.5, and for `CREDENTIALS_save()`, see section 4.1):

```
CREDENTIALS *new_creds = NULL;
const char *subject = "/CN=test-genCMPClient";
EVP_PKEY *new_key = KEY_new("EC:prime256v1");
X509_EXTENSIONS *exts = …
err = CMPclient_bootstrap(ctx, &new_creds, new_key, subject, exts);
if (err == 0) {
    const CREDENTIALS *creds = new_creds;
    const char *file = "certs/new.p12";
    const char *source = NULL /* plain file */;
    const char *desc = " newly enrolled certificate and related key and chain";
    if (!CREDENTIALS_save(creds, file, file, OPTIONAL source, OPTIONAL desc))
        goto err;
}
```

3.5 CMPclient_revoke

The function `CMPclient_revoke()` performs certificate revocation using the CMP command '`rr`', see [LCMPP section 4.2]. Any polling for the response is handled under the hood.

Param.	Type	Name	Meaning
	CMP_CTX *	ctx	CMP context to use
	const X509 *	cert	Certificate to be revoked
	int	reason	Revocation reason code, as defined in `openssl/x509v3.h`

3.6 CMPclient_caCerts

The function `CMPclient_caCerts()` obtains a list of CA certificates from the server and verifies that they are non-expired CA certificates. This function, as well as the there following ones, is implemented using the CMP command '`genm`' and performs any needed polling for the response under the hood.

If the obtained certificates are going to be used as trust anchors, special care should be taken beforehand when providing credentials to `CMPclient_prepare()` for authenticating the server. If authentication is certificate-based, after calling `CMPclient_caCerts()` successfully, `OSSL_CMP_CTX_get0_validatedSrvCert()` should be used to obtain the server certificate and then perform an authorization check based on it.

Param.	Type	Name	Meaning
	`CMP_CTX *`	`ctx`	CMP context to use
	`STACK_OF(X509) **`	`out`	Pointer to variable to obtain the list of certificates. The list returned may be empty.

3.7 CMPclient_certReqTemplate

The function `CMPclient_certReqTemplate()` requests from the server any preferences of the PKI for certificate requests, namely a CRMF template and optionally related key specifications. Each of them may be `NULL` to indicate that there are no such preferences.
The request may refer to a certificate profile set using `CMPclient_add_certProfile()`.

Param.	Type	Name	Meaning
	`CMP_CTX *`	`ctx`	CMP context to use
	`OSSL_CRMF_CERTTEMPLATE *`	`certTemplate`	Pointer to variable to obtain any CRMF template
`OPTIONAL`	`OSSL_CMP_ATAVS **`	`keySpec`	Pointer to variable to obtain any key specifications

3.8 CMPclient_rootCaCert

The function `CMPclient_rootCaCert()` obtains from the server an update on the given root CA certificate or `NULL` if there is no update. If available, any provided forward and backward link certificates are used to verify the certificate update, and optionally they can be retrieved, too.

The caveats given above for `CMPclient_caCerts()` apply here as well.

Param.	Type	Name	Meaning
	`CMP_CTX *`	`ctx`	CMP context to use
	`const X509 *`	`oldWithOld`	Root CA certificate for which an update may be given
	`X509 **`	`newWithNew`	Pointer to variable to obtain the CA certificate update
`OPTIONAL`	`X509 **`	`newWithOld`	Pointer to variable to obtain any forward link certificate
`OPTIONAL`	`X509 **`	`oldWithNew`	Pointer to variable to obtain any backward link cert

3.9 CMPclient_crlUpdate

The function `CMPclient_crlUpdate()` obtains from the server either the latest CRL according to a distribution point name or issuer name taken from either a given certificate or a given CRL. If it is no newer than the given CRL, no CRL is transmitted and a `NULL` pointer is provided.

Param.	Type	Name	Meaning
	`CMP_CTX *`	`ctx`	CMP context to use
`OPTIONAL`	`X509 *`	`cert`	certificate to take dist point name or issuer name from
`OPTIONAL`	`const X509_CRL *`	`last_crl`	CRL on which an update may be given
	`X509_CRL **`	`crl`	Pointer to variable to obtain the new CRL

3.10 CMPclient_snprint_PKIStatus

The function `CMPclient_snprint_PKIStatus()` copies any detailed status or error information provided by the server into the given string buffer. If returns the buffer pointer on success and `NULL` on error.

Param.	Type	Name	Meaning
	`CMP_CTX *`	`ctx`	CMP context to use
	`const char *`	`buf`	Pointer to buffer receiving the string output
	`size_t`	`bufsize`	Size of the buffer (including the trailing NUL character)

3.11 CMPclient_reinit

The function `CMPclient_reinit()` re-initializes the given CMP context. It must be called between any of the above activities. Any of the pointers provided for the above parameters like `ctx`, `cmp_truststore`, `server`, `tls`, `new_key`, and `subject` may then be reused for subsequent activities.

Param.	Type	Name	Meaning
	`CMP_CTX *`	`ctx`	CMP context to re-initialize

3.12 CMPclient_finish

The function `CMPclient_finish()` deallocates the given CMP context, deallocating all internal data but not the structures passed in via the functions described before. Any of the pointers provided for the above parameters like `cmp_truststore`, `tls`, and `new_key` must be deallocated when not needed any more.

Param.	Type	Name	Meaning
`OPTIONAL`	`CMP_CTX *`	`ctx`	CMP context to deallocate

Example use (for the various `_free()` functions, see sections 3.16 and 4):

```
CMPclient_finish(ctx);
CREDENTIALS_free(new_creds);
EXTENSIONS_free(exts);
KEY_free(newkey);
TLS_free(tls);
CREDENTIALS_free(tls_creds);
STORE_free(tls_truststore);
STORE_free(new_cert_truststore);
STORE_free(cmp_truststore);
CREDENTIALS_free(creds);
LOG_close();
```

3.13 Logging

When an important activity is performed or an error occurs, some more detail should be provided for debugging and auditing purposes. An application can obtain this information by providing a callback function, which is called on error with `component`, `file`, `lineno`, and `msg` arguments that may provide a component identifier, a file path name and a line number indicating the source code location and a string describing the nature of the event.
Even when an activity is successful some warnings may be useful and some degree of logging may be required. Therefore we have extended the type of the logging callback function of CMPforOpenSSL by a `level` argument indicating the severity level, such that error, warning, info, debug, etc. can be treated differently. Moreover, the callback function may itself do non-trivial tasks like writing to a log file, which in turn may fail. Thus we utilize a Boolean return type indicating success or failure.

```
typedef enum { false = 0, true = 1 } bool;
typedef int severity;
#define LOG_EMERG   0
#define LOG_ALERT   1
#define LOG_CRIT    2
#define LOG_ERR     3
#define LOG_WARNING 4
#define LOG_NOTICE  5
#define LOG_INFO    6
#define LOG_DEBUG   7
#define LOG_TRACE   8
typedef bool (*LOG_cb_t) (OPTIONAL const char *func,
                          OPTIONAL const char *file, int lineno,
                          severity level, const char *msg);
```

The `LOG_default()` function prints more critical messages like errors and warnings to `stderr`, while less critical ones like info and debug messages are printed to `stdout`. In addition, it sends messages to `syslog`.

```
bool LOG_default(OPTIONAL const char *func, OPTIONAL const char *file, int lineno,
                 severity level, const char *msg);
```

The `LOG_set_verbosity()` function sets sets the verbosity of `LOG_default()`. The `level` parameter defines the minimal severity of messages to be output. The default is `LOG_INFO`.

```
void LOG_set_verbosity(severity level);
```

The `LOG_set_name()` function sets the application name printed by the default log output. The string pointed to by the `name` parameter must not be deallocated as long as logging is used. The default is `"SecUtils"` .

```
void LOG_set_name(OPTIONAL const char *name);
```

The `LOG()` function logs the message specified by the parameter `fmt` and optionally further ones as with `printf()`. The parameter `func` optionally gives the name of the reporting function or component, the parameter `file` optionally gives the current source file path name, the parameter `lineno` gives the current line number or `0`, and the parameter `level` gives the nature of the message. The function returns true `success` and `false` on failure.

```
bool LOG(OPTIONAL const char *func, OPTIONAL const char *file, int lineno,
         severity level, const char *fmt, ...);
```

For convenient use of `LOG()` the Security Utilities library defines various macros such as

```
#define LOG_FUNC_FILE_LINE                      OPENSSL_FUNC, OPENSSL_FILE, OPENSSL_LINE
#define FL_ERR LOG_FUNC_FILE_LINE, LOG_ERR      /* An error message. */
#define FL_WARN LOG_FUNC_FILE_LINE, LOG_WARNING /* A warning message. */
#define FL_INFO LOG_FUNC_FILE_LINE, LOG_INFO    /* A general information message. */
#define FL_DEBUG LOG_FUNC_FILE_LINE, LOG_DEBUG  /* A message useful for debugging. */
```

When all CMP client activity is finished the log should be closed using the following function, which flushes any pending log output and deallocates log-related resources.

```
void LOG_close(void);
```

3.14 Message transfer callback function

The usual way of transferring CMP messages is via HTTP (see also [RFC6712]), with or without TLS. As mentioned in section 2, this transfer mode is therefore the default. Yet it is possible to provide as the `transfer_fn` argument of the `CMPclient_prepare()` function (see section 3.1) a non-`NULL` function pointer of type `OSSL_CMP_transfer_cb_t`. This callback function takes as parameters the current CMP context structure, the request message to be sent and the address of a result variable to which it shall assign on success the response message received at the end of the transfer. The function shall send the request to some server and try to obtain the corresponding response from the server. It shall return an error code of type `CMP_err`. If needed, the application may also provide a further argument to the

callback function, using the CMPforOpenSSL functions `OSSL_CMP_CTX_set_transfer_cb_arg()` and `OSSL_CMP_CTX_get_transfer_cb_arg()`. This API design gives full freedom for implementing whatever method of transferring methods, including file-based ones.

```
typedef OSSL_CMP_MSG *(*OSSL_CMP_transfer_cb_t)(CMP_CTX *ctx,
                                                const OSSL_CMP_MSG *req);
```

3.15 Certificate checking callback function

When the CMP client receives from the server a newly enrolled certificate it should have the possibility to inspect the certificate to check whether it fulfills the given expectations. Depending on the outcome of this check, the client can signal acceptance or rejection of the certificate to the server via the '`certConf`' CMP message.

The CMPforOpenSSL library just checks that the public key in the new certificate matches the key used in the request. In addition one can provide via the `OSSL_CMP_CTX_set_certConf_cb()` function a function pointer of type `OSSL_CMP_certConf_cb_t`. This callback function takes as parameters the current CMP context structure, the newly enrolled certificate to be checked, any CMP failure bits (see [RFC 9810, section 5.2.3]) already determined by the library, and a pointer to the string result variable to which it may assign on error a string describing why it rejects the given certificate. The function shall return `0` on acceptance or CMP failure bits with indices between `0` and `OSSL_CMP_PKIFAILUREINFO_MAX` (= `26`) indicating the reason(s) for rejection. The application may also provide a further, implicit argument to the callback function via the CMPforOpenSSL function `OSSL_CMP_CTX_set_certConf_cb_arg()`. This argument can be retrieved using `OSSL_CMP_CTX_get_certConf_cb_arg()`.

If the `new_cert_truststore` argument of the `CMPclient_prepare()` is not `NULL` the callback function `OSSL_CMP_certConf_cb()` provided by CMPforOpenSSL will be selected, which uses this argument as a trust store for validating the newly enrolled certificate.

This API design gives full freedom for implementing arbitrary checks on newly enrolled certificates, for instance whether the subject DN is as expected and/or all required X.509 extensions have been set, in addition to validating the certificate relative to some trust store.

```
typedef int (*OSSL_CMP_certConf_cb_t)(CMP_CTX *ctx, const X509 *cert,
                                      int fail_info, const char **txt);
```

3.16 Component credentials

Like CMPforOpenSSL, for key material and other core crypto data structures we re-use the ones defined by the underlying OpenSSL library, as far as possible, but one was missing.
It is very useful to have an abstraction that combines the key material a component has for authenticating itself in a single data structure. For signature-based authentication this consists of a private key of OpenSSL type `EVP_PKEY`, which can refer to a key held in a hardware key store via a crypto provider [OpenSSL-provider] or a legacy crypto engine [OpenSSL-engine], the current certificate (of OpenSSL type `X509`) including the corresponding public key, and optionally the chain of its issuer certificates towards the respective root CA (of OpenSSL type `STACK_OF(X509))`. For authentication with password-based MAC (PBM) the credentials include the password and optionally a reference value that may be needed, similarly to a user name, to identify which password to use.
The resulting data structure, which we call `CREDENTIALS`, will be used by the CMP client on the one hand for itself, namely for signing/protecting CMP messages and optionally for authenticating itself as TLS client, and on the other hand to convey the output of certificate enrollment, where the newly enrolled certificate is bundled with the related private key and any chain of certificates provided by the server.

```
typedef struct credentials {
    OPTIONAL EVP_PKEY *pkey;
    OPTIONAL X509     *cert;
    OPTIONAL STACK_OF(X509) *chain;
    OPTIONAL char *pwd;
    OPTIONAL char *pwdref;
} CREDENTIALS;
```

We define the following core functions dealing with credentials.

The function `CREDENTIALS_new()` constructs a set of credentials from its components (i.e., a private key, a related certificate, and optionally a chain, and/or a password and optionally its reference value) and returns on a pointer to the newly allocated structure on success or `NULL` on failure (i.e., out of memory). On success the reference counter of the first three arguments are incremented and the last two arguments are copied. This means that the caller can deallocate all provided arguments immediately and in any case should wipe/erase the contents of the `pwd` parameter right away for security reasons.

Param.	Type	Name	Meaning
OPTIONAL	const EVP_PKEY *	pkey	Private key to include, which may be from a provider or legacy crypto engine
OPTIONAL	const X509 *	cert	Related certificate to include
OPTIONAL	const STACK_OF(X509) *	chain	Chain of the given certificate
OPTIONAL	const char *	pwd	Password to use for PBM etc.
OPTIONAL	const char *	pwdref	Reference for identifying the password

The function `CREDENTIALS_free()` takes a pointer to a credentials structure when not needed any more, deallocates its components (using among others `KEY_free()`, which wipes the private key, and `OPENSSL_cleanse()` to wipe the secret/password), and then deallocates the structure itself. It has no return value.

```
void CREDENTIALS_free(OPTIONAL CREDENTIALS *creds);
```

Since the `CREDENTIALS` data type is opaque some selector functions are needed:

```
X509 *CREDENTIALS_get_cert(const CREDENTIALS *creds);
STACK_OF(X509) *CREDENTIALS_get_chain(const CREDENTIALS *creds);
```

4. Support functionality

This section describes useful auxiliary functions for preparing the parameters of the above core functions. While this could be done directly using the rather low-level OpenSSL API, it is cumbersome and error-prone to identify and directly use the OpenSSL functions directly. Therefore we introduce this intermediate level for convenience, such that the typical use cases can be implemented without needing to know any details of the underlying CMPforOpenSSL and OpenSSL API. As mentioned before, experienced programmers may still make use of those lower-level functions in order to cover any special needs.

4.1 CREDENTIALS helpers

Since certificates as well as private keys (unless they are held in a hardware key store) are usually held in files, we provide functions for loading the components of credentials from files and for saving them in files. For now, we focus here on the PKCS#12 file format because all components of a `CREDENTIALS` structure can be easily and conveniently managed in a single PKCS#12 structure. Other formats, such as PEM, are partially supported.

The function `CREDENTIALS_load()` reads from the file given in the `certs` argument (if not `NULL`) the primary certificate, which is taken as the `cert` component, plus any further ones, which are taken as the `chain` component. In case the `source` argument is `NULL` or begins with `"pass:"`, it reads the private key from the file given in the `key` argument (if not `NULL`), where the `source` argument may refer to a password in the form `"pass:<pwd>"` that may be needed to decrypt the file contents including the private key. If the `certs` and `key` arguments are equal the credentials are jointly read from the same file, which is expected in PKCS#12 format, else for each file the format may be PEM, PKCS#12, or ASN.1 (DER). In case the `source` argument begins with `"engine:"`, it loads a reference to the private key with the identifier given in the `key` argument, where the rest of the `source` argument gives the identifier of the legacy crypto engine to use (while the remaining credentials components are loaded from the file without decrypting it). The respective crypto engine must already have been parameterized and initialized in an engine-specific way with the respective legacy OpenSSL mechanisms. These are described for instance in [OpenSSL-engine] and are removed with OpenSSL 4.0.

The function internally calls `CREDENTIALS_new()` to construct a `CREDENTIALS` structure and returns the pointer to it on success, or `NULL` otherwise. In case of errors optionally the string held in the optional `desc` parameter is used for forming more descriptive error messages.

```
CREDENTIALS *CREDENTIALS_load(OPTIONAL const char *certs, OPTIONAL const char *key,
                              OPTIONAL const char *source, OPTIONAL const char *desc);
```

Example use for certificates and a private key read from a PKCS#12 file:

```
const char *certs = "certs/cmp_signer.p12";
const char *key = certs;
const char *source = "pass:12345";
const char *desc = "credentials for CMP level"
CREDENTIALS *creds = CREDENTIALS_load(certs, key, source, desc);
```

Example use where the private key is held in HW and its reference is loaded via PKCS#11 using a legacy crypto engine (while the actual key is held, e.g., on a smart card or a TPM chip):

```
const char *tls_certs = "certs/tls.p12";
const char *tls_pkey = "my-key-ID;type=private;pin-value=1234";
const char *tls_source = "engine:pkcs11";
const char *tls_desc = "credentials for TLS level"
CREDENTIALS *tls_creds = CREDENTIALS_load(tls_certs, tls_pkey, tls_source,
                f                         tls_desc);
```

The function `CREDENTIALS_save()` writes the certificate components of the given credentials data structure `creds` to the file given as the `certs` argument (unless it is `null`). If the `certs` and `key` arguments are equal the certificates and the private key are written jointly to the same PKCS#12 file, else they are written to PEM files (where the certificates are not encrypted). In case the `source` argument is `NULL` or begins with `"pass:"`, it stores the private key in the given `key` file (unless it is `null`). , where the `source` argument may refer to a password in the form `"pass:<pwd>"` that is then used to encrypt the private key (together with the related certificates when stored jointly in a PKCS#12 file) before storing it. In case the `source` argument begins with `"engine:"`, it assumes that the private key is held in a legacy crypto engine and there is no need and neither a possibility for it to save the key (nor to encrypt the related certificates written to a file). The function returns `true` on success and `false` otherwise. In case of errors optionally the string held in the optional `desc` parameter is used for forming error messages.

```
bool CREDENTIALS_save(OPTIONAL const CREDENTIALS *creds,
                      OPTIONAL const char *certs, OPTIONAL const char *key,
                      OPTIONAL const char *source, OPTIONAL const char *desc);
```

An example use has already been given in section 3.4.

Functions for loading and storing individual certificates and for loading CSRs and CRLs:

```
X509 *CERT_load(const char *file, OPTIONAL const char *pass, OPTIONAL const char *desc);
bool CERT_save(const X509 *cert, const char *file, OPTIONAL const char *desc);
X509_REQ *CSR_load(const char *file, OPTIONAL const char *desc);
X509_CRL *CRL_load(const char *file, int total_timeout, OPTIONAL const char *desc);
```

When storing a certificate in a file with the given name the format is determined from the file name extension and can be PEM, DER, or PKCS#12. In case of errors the string held in the optional `desc` parameter is used for forming more descriptive error messages.

Functions for loading and saving lists of certificates are described below.

4.2 X509_STORE helpers

As the above core functions reuse the OpenSSL trust store data structure of type `X509_STORE` and such a structure is non-trivial to manage we provide helper functions for this purpose. For instance, the store needs to be initialized with trusted certificates and optionally with many other verification parameters such as Certificate Revocation Lists (CRLs), URLs of Certificate Distribution Points (CDPs), and Online Certificate Status Protocol (OCSP) responders. Certificates are typically held in files and thus need to be loaded while CRLs are typically retrieved online from CDPs and then cached in files or in memory.

The function `STORE_load()` sets up a new trust store with the certificates held in the PEM, DER, or PKCS#12 file(s) with the comma-separated list of names given as the `trusted_certs` argument. It enables diagnostic output in the log that is very helpful for debugging in case certificate verification fails. It does not enable certificate status checks. Specific OpenSSL certificate verification parameters may be given in the `vpm` parameter. The function returns the pointer to the constructed trust store on success, or `NULL` otherwise. In case of errors the string held in the optional `desc` parameter is used for forming error messages.

```
X509_STORE *STORE_load(const char *trusted_certs, OPTIONAL const char *desc,
                       OPTIONAL X509_VERIFY_PARAM *vpm);
```

Example use:

```
const char *trusted_certs = "certs/trusted/RootCAv10.crt,trusted2.crt";
const char *desc = "trusted certs for CMP level";
X509_STORE *truststore = STORE_load(trusted_certs, OPTIONAL desc, NULL);
```

The function `CERTS_load()` loads the certificate(s) held in the PEM, DER, or PKCS#12 file(s) with the comma-separated list of file names in the `files` argument and returns the pointer to the loaded list of certificates on success, or `NULL` otherwise. These certificates can be used as auxiliary untrusted certs when constructing a `CMP_CTX` or `TLS_CTX`. The `type_CA` parameter specifies the required certificate type: `1` for CA certificates, `0` for EE certificates, or `-1` for no restriction. Specific verification parameters may be given via `vpm`. In case of errors the string held in the optional `desc` parameter is used for forming more descriptive error messages.

```
STACK_OF(X509) *CERTS_load(const char *files, OPTIONAL const char *desc,
                           int type_CA, OPTIONAL const X509_VERIFY_PARAM *vpm);
```

The function `CERTS_save()` stores the given certificate(s) in a file with the given name, where the format is determined from the file name extension and can be PEM, DER, or PKCS#12. In case of errors the string held in the optional `desc` parameter is used for forming more descriptive error messages.

```
int CERTS_save(const STACK_OF(X509) *certs, const char *file, OPTIONAL const char *desc);
```

The function `CERTS_free()` deallocates any given list of certificates. It has no return value.

```
void CERTS_free(OPTIONAL STACK_OF(X509) *certs);
```

The function `CRLs_load()` loads the CRL(s) held in the DER or PEM file(s) with the comma-separated list of file names in the `files` argument and returns the loaded list of CRLs on success, or `NULL` otherwise. The `timeout` parameter specifies the number of seconds an HTTP transaction (if needed) may take, or `0` for infinite or `-1` for default. In case of errors the string held in the optional `desc` parameter is used for forming more descriptive error messages.

```
STACK_OF(X509_CRL) *CRLs_load(const char *files, int timeout, OPTIONAL const char *desc);
```

The function `STORE_add_crls()` adds an optional list of CRLs to the given trust store and enables CRL-based status checks for end-entity certificates.

```
bool STORE_add_crls(X509_STORE *truststore, OPTIONAL const STACK_OF(X509_CRL) *crls);
```

The function `CRLs_free()` deallocates any given list of CRLs. It has no return value.

```
void CRLs_free(OPTIONAL STACK_OF(X509_CRL) *crls);
```

The function `STORE_set_parameters()` sets various optional verification parameters in the given trust store `truststore`; in more detail, it

- takes over any given OpenSSL certificate verification parameters `vpm`
- demands certificate status checks in case any of the OCSP- or CRL-related options is set. If in addition the `full_chain` option is set then all (except root) certificates are checked, else only end-entity certificates, i.e., the first certificate of each chain.
  For each certificate for which the status check is demanded the verification function will try to obtain the revocation status first via OCSP stapling (which is applicable only for TLS) if enabled, then from any locally available CRLs, then from any OCSP responders if enabled, and finally from any certificate distribution points (CDPs) if enabled.
  Verification fails if no valid and current revocation status can be determined or the status indicates that the certificate has been revoked.
- enables OCSP stapling, which makes sense only for TLS, if `try_stapling` is set
- adds CRLs provided in the `crls` argument and in this case enables CRL-based checks,
- enables CRL-based checks in case using CDP entries in certificates is enabled via the `use_CDP` argument or a static list of comma-separated URLs for fetching CRLs is given as the `cdps` argument (used as fallback) where the `crls_timeout` parameter gives the number of seconds fetching a CRL may take, or `0` for infinite or `-1` for default (= `10`), and
- enables fetching OCSP responses in case the use of AIA OCSP entries in certificates is enabled via the `use_AIA` argument or a static list of comma-separated OCSP responder URLs is given as the `ocsp` argument (which is used as fallback) where the `ocsp_timeout` parameter gives the number of seconds fetching an OCSP response may take, or `0` for infinite or `-1` for default (= `10`).

The function returns `true` on success and `false` otherwise.

```
bool STORE_set_parameters(X509_STORE *truststore, OPTIONAL const X509_VERIFY_PARAM *vpm,
```

```
                                bool full_chain, bool try_stapling,
                                OPTIONAL const STACK_OF(X509_CRL) *crls,
                                bool use_CDP, OPTIONAL const char *cdps, int crls_timeout,
                                bool use_AIA, OPTIONAL const char *ocsp, int ocsp_timeout);
```

The function `STORE_set_crl_callback()` sets a CRL fetching callback function and optional argument in the given trust store, which may be used for instance to implement CRL caching. If the `use_CDP` parameter has been set in the trust store the callback is called for each HTTP URL found in the CDP entries of a certificate to be verified. If all these are inconclusive then it is called once more with a `NULL` URL (such that the callback may try getting a CRL based on any further information contained in the certificate being checked). The `store` parameter references the certificate trust store to be extended, the `crl_cb` parameter provides the callback function to use, or null for default (which is `CONN_load_crl_http()`), and the `crl_cb_arg` may be used to provide an argument to be passed to the callback function. It returns `true` on success and `false` otherwise.

```
typedef X509_CRL *(*CONN_load_crl_cb_t)(OPTIONAL void *arg,
                                        OPTIONAL const char *url, int timeout,
                                        const X509 *cert, OPTIONAL const char *desc);
bool STORE_set_crl_callback(X509_STORE *store,
                            OPTIONAL CONN_load_crl_cb_t crl_cb,
                            OPTIONAL void *crl_cb_arg);
```

The `STORE_set1_host_ip()` function is used by `CMPclient_setup_HTTP()` as described there. It disables host name/address verification if the `host` and `ip` parameters are `NULL`, otherwise enables host verification in the given trust store (typically returned from `TLS_new()`) and defines the server host name and/or IP address to be expected for a TLS connection, where the host name will also be used for Server Name Indication (SNI) according to RFC 3546 section 3.1. It is crucial for TLS clients to verify the identity of the host to connect to. The parameter `host` optionally gives the host DNS name to be expected, while the parameter `ip` optionally gives the host IP address to be expected. Both parameters may be given in the form of a URL, from which the hostname part is copied and the rest is ignored. If both `host` and `ip` are non-`NULL` and the strings resulting from them are equal, the function tries to interpret the strings first as an IP address then as a domain name. The function returns `true` on success and `false` otherwise..

```
bool STORE_set1_host_ip(X509_STORE *store, OPTIONAL const char *host, OPTIONAL const char
*ip);
```

Further non-default trust store parameters may be set as far as needed using the various respective low-level OpenSSL functions.
Example for setting up a trust store with use of statically and dynamically obtained CRLs:

```
X509_STORE *truststore = …;
const X509_VERIFY_PARAM *vpm = NULL;
bool full_chain = true;
bool try_stapling = false;
const char *file =
     "certs/crls/EJBCA-InfrastructureIssuingCAv10.crl, "
     "certs/crls/EjBCA-ECCRootAv10.crl";
const char *desc = "CRLs for CMP level";
const STACK_OF(X509_CRL) *crls = CRLs_load(file, -1, NULL);
bool use_CDP = true;
const char *cdps = NULL;
int crls_timeout = -1;
bool use_AIA = false;
const char *ocsp = NULL;
int ocsp_timeout = -1;
bool success = STORE_set_parameters(truststore, vpm, full_chain, try_stapling, crls,
                                    use_CDP, cdps, crls_timeout,
                                    use_AIA, ocsp, ocsp_timeout);
```

The function `STORE_free()` deallocates any given trust store. It has no return value.

```
void STORE_free(OPTIONAL X509_STORE *truststore);
```

4.3 EVP_PKEY helpers

The function `KEY_new()` generates a new private key of OpenSSL type `EVP_PKEY` according to the specification given as its `spec` argument, which may be of the form "`RSA:<length>`" or "`EC:<curve>`". The RSA key length must be between 1024 and 8192 bits. The available ECC curves can be shown with the command `openssl ecparam -list_curves`. The function returns the new key on success and `NULL` otherwise.

```
EVP_PKEY *KEY_new(const char *spec);
```

An example use has been given in section 3.4.

Keys accessed via a crypto provider or legacy crypto engine need to be generated by other means.

The `KEY_load()` function loads a private key from the given `file` or `engine`. The file format can be PEM, DER, or PKCS#12. The parameter `pass` may provide a password (optionally preceded by `"pass:"`) needed for decrypting the file content. In case of errors the string held in the optional `desc` parameter is used for forming more descriptive error messages.

```
EVP_PKEY *KEY_load(OPTIONAL const char *file, OPTIONAL const char *pass,
                   OPTIONAL const char *engine, OPTIONAL const char *desc);
```

The function `KEY_free()` deallocates the given `pkey` and wipes its representation in memory if it is SW-based. It has no return value. For HW-based keys it just deallocates the reference.

```
void KEY_free(OPTIONAL EVP_PKEY *pkey);
```

4.4 SSL_CTX helpers

The function `TLS_new()` sets up a new OpenSSL `SSL_CTX` structure with reasonable default parameters for TLS (typically HTTPS client) connections. Its optional arguments are the trust store `truststore` to use for authenticating the peer (typically a TLS server), a list of intermediate certificates `untrusted` that may be helpful when building the own (typically TLS client) certificate chain and while checking stapled OCSP responses, the credentials `creds` to use for authenticating to the peer, and the enabled cipher suites. All these parameters are not consumed, so should be deallocated by the caller.
If the `creds` argument is given the function checks that its certificate matches its private key and tries to build a chain from the certificate using the `truststore` and `untrusted` certificates (as far as given) to be used for authenticating to the peer. If this fails it issues a warning and uses the chain in the `creds` argument (if included) as fallback.
The available cipher suite names can be shown with the command `openssl list -cipher-algorithms`. See also [OpenSSL-ciphers] how to specify them more abstractly. The security level ranges from `0` (lowest) to `5`. If `-1` is given, a sensible value is determined from the cipher list if provided, else the OpenSSL default is used (which is currently `1`). For details see [OpenSSL-sec-level]. The function returns the pointer to the new structure on success, or `NULL` otherwise. Further non-default TLS parameters may be set as far as needed using the various respective low-level OpenSSL functions.

```
SSL_CTX *TLS_new(OPTIONAL X509_STORE *truststore,
                 OPTIONAL const STACK_OF(X509) *untrusted,
                 OPTIONAL const CREDENTIALS *creds,
                 OPTIONAL const char *ciphers, int security_level);
```

The function `TLS_free()` deallocates the given TLS context `tls` . It has no return value.

```
void TLS_free(OPTIONAL SSL_CTX *tls);
```

4.5 X509_EXTENSIONS helpers

The function `EXTENSIONS_new()` initiates a list of X.509 extensions, which has OpenSSL type `X509_EXTENSIONS`, to be used in certificate enrollment. It returns the pointer to the new structure on success, or `NULL` otherwise.

```
X509_EXTENSIONS *EXTENSIONS_new(void);
```

The function `EXTENSIONS_add_SANs()` appends to the given list of X.509 extensions `exts` a list of Subject Alternative Names (SANs) given as a string `spec` of comma-separated domain names, IP addresses, and/or URIs optionally preceded by "`critical,`" to mark them critical. It returns `true` on success and `false` otherwise.

```
bool EXTENSIONS_add_SANs(X509_EXTENSIONS *exts, const char *spec);
```

The function `EXTENSIONS_add_ext()` appends to the given list of X.509 extensions `exts` an extension of the given type, e.g., `"basicConstraints"`, `"keyUsage"`, `"extendedKeyUsage"`, or `"certificatePolicies"`. Its value is given as a string `spec` of comma-separated names or OIDs optionally preceded by "`critical,`" to mark the extension critical. The specification may refer to further details specified in the style of OpenSSL configuration file sections (see [OpenSSL-ext-config]), which can be provided via the optional `sections` parameter. The function returns `true` on success, `false` otherwise.
Possible values for basic key usages are: `"digitalSignature"`, `"nonRepudiation"`, `"keyEncipherment"`, `"dataEncipherment"`, `"keyAgreement"`, `"keyCertSign"`, `"cRLSign"`, `"encipherOnly"`, and `"decipherOnly"`. For a list of generally defined Extended Key Usage OIDs, see [OID-ref].

```
bool EXTENSIONS_add_ext(X509_EXTENSIONS *exts, const char *name,
                        const char *spec, BIO *sections);
```

Example use:

```
X509_EXTENSIONS *exts = EXTENSIONS_new();
BIO *policy_sections = BIO_new(BIO_s_mem());
bool success = exts != NULL && policy_sections != NULL &&
    EXTENSIONS_add_SANs(exts, "localhost, 127.0.0.1, 192.168.0.1") &&
    EXTENSIONS_add_ext (exts, "keyUsage", "critical, digitalSignature", NULL) &&
    EXTENSIONS_add_ext (exts, "extendedKeyUsage", "critical, clientAuth, "
                              "1.3.6.1.5.5.7.3.1" /* serverAuth */, NULL) &&
    BIO_printf(policy_sections, "%s",
               "[pkiPolicy]\n"
               "  policyIdentifier = 1.3.6.1.4.1.4329.38.4.2.2\n"
               "  CPS.1 = http://www.my-company.com/pki-policy/\n"
               "  userNotice = @notice\n"
               "[notice]\n"
               "  explicitText=policy text\n") > 0 &&
    EXTENSIONS_add_ext(exts, "certificatePolicies",
                       "critical, @pkiPolicy", policy_sections);
BIO_free(policy_sections);
```

The function `EXTENSIONS_free()` deallocates the given structure `exts`. It has no return value.

```
void EXTENSIONS_free(OPTIONAL X509_EXTENSIONS *exts);
```

5. Appendix: C header file

```
/*!*****************************************************************************
 * @file   genericCMPclient.h
 * @brief  generic CMP client library API
 *
 * @author David von Oheimb, Siemens AG
 *
 * Copyright (c) Siemens AG, 2018-2025.
 * Licensed under the Apache License, Version 2.0
 * SPDX-License-Identifier: Apache-2.0
*******************************************************************************/

#ifndef GENERIC_CMP_CLIENT_H
# define GENERIC_CMP_CLIENT_H

/* for low-level CMP API, in particular, type CMP_CTX */
# include <openssl/cmp.h>

# include <secutils/credentials/credentials.h>
# include <secutils/credentials/cert.h>
# include <secutils/util/log.h>

/* for abbreviation and backward compatibility: */
typedef OSSL_CMP_CTX CMP_CTX;
typedef OSSL_CMP_severity severity;


typedef int CMP_err;
# define CMP_OK 0
# define CMP_R_OTHER_LIB_ERR 99
# define CMP_R_LOAD_CERTS         255
# define CMP_R_LOAD_CREDS         254
# define CMP_R_GENERATE_KEY       253
# define CMP_R_STORE_CREDS        252
# define CMP_R_RECIPIENT          251
# define CMP_R_INVALID_CONTEXT    250
# define CMP_R_INVALID_PARAMETERS CMP_R_INVALID_ARGS
# define CMP_R_INVALID_PARAMETERS 249/* further error codes are defined in cmperr.h */

# define CMP_IR    0
# define CMP_CR    2
# define CMP_P10CR 4
# define CMP_KUR   7

# ifndef __cplusplus
typedef enum { false = 0, true = 1 } bool; /* Boolean value */
# endif

#define OPTIONAL /* marker for non-required parameter, i.e., NULL allowed */

/* private key and related certificate, plus optional chain */
typedef struct credentials {
    OPTIONAL EVP_PKEY *pkey;        /* can refer to HW key store via provider/engine */
    OPTIONAL X509     *cert;        /* related certificate */
    OPTIONAL STACK_OF(X509) *chain; /* intermediate/extra certs for cert */
    OPTIONAL const char *pwd;       /* alternative: password (shared secret) */
    OPTIONAL const char *pwdref;    /* reference identifying the password */
} CREDENTIALS;

typedef int severity;
# define LOG_EMERG   0
# define LOG_ALERT   1
# define LOG_CRIT    2
# define LOG_ERR     3
# define LOG_WARNING 4
# define LOG_NOTICE  5
# define LOG_INFO    6
# define LOG_DEBUG   7
# define LOG_TRACE   8

typedef bool (*LOG_cb_t) (OPTIONAL const char *func,
                          OPTIONAL const char *file, int lineno,
                          severity level, const char *msg);
```

```
/* CMP client core functions */
/* should be called once, as soon as the application starts */
CMP_err CMPclient_init(OPTIONAL const char *name, OPTIONAL LOG_cb_t log_fn);

/* must be called first */
CMP_err CMPclient_prepare(CMP_CTX **pctx,
                          OPTIONAL OSSL_LIB_CTX *libctx, OPTIONAL const char *propq,
                          OPTIONAL LOG_cb_t log_fn,
                          OPTIONAL X509_STORE *cmp_truststore,
                          OPTIONAL const char *recipient,
                          OPTIONAL const STACK_OF(X509) *untrusted,
                          OPTIONAL const CREDENTIALS *creds,
                          OPTIONAL X509_STORE *creds_truststore,
                          OPTIONAL const char *digest,
                          OPTIONAL const char *mac,
                          OPTIONAL OSSL_CMP_transfer_cb_t transfer_fn, int total_timeout,
                          OPTIONAL X509_STORE *new_cert_truststore, bool implicit_confirm);
/* must be called next if the transfer_fn is NULL and no existing connection is used */
CMP_err CMPclient_setup_HTTP(CMP_CTX *ctx, const char *server, const char *path,
                             int keep_alive, int timeout, OPTIONAL SSL_CTX *tls,
                             OPTIONAL const char *proxy, OPTIONAL const char *no_proxy);
/* must be called alternatively if transfer_fn is NULL and existing connection is used */
CMP_err CMPclient_setup_BIO(CMP_CTX *ctx, BIO *rw, OPTIONAL const char *path,
                            int keep_alive, int timeout);

/* call optionally before requests; name may be UTF8-encoded string */
/* This calls OSSL_CMP_CTX_reset_geninfo_ITAVs() if name == NULL */
CMP_err CMPclient_add_certProfile(CMP_CTX *ctx, OPTIONAL const char *name);

/* only one of the following activities can be called next */

/* the structure returned in *new_creds must be deallocated by the caller */
CMP_err CMPclient_imprint(CMP_CTX *ctx, CREDENTIALS **new_creds,
                          const EVP_PKEY *newkey, const char *subject,
                          OPTIONAL const X509_EXTENSIONS *exts);
CMP_err CMPclient_bootstrap(CMP_CTX *ctx, CREDENTIALS **new_creds,
                            const EVP_PKEY *newkey, const char *subject,
                            OPTIONAL const X509_EXTENSIONS *exts);
CMP_err CMPclient_pkcs10(CMP_CTX *ctx, CREDENTIALS **new_creds,
                         const X509_REQ *p10csr);
CMP_err CMPclient_update(CMP_CTX *ctx, CREDENTIALS **new_creds,
                         OPTIONAL const EVP_PKEY *newkey);
CMP_err CMPclient_update_anycert(CMP_CTX *ctx, CREDENTIALS **new_creds,
                                 OPTIONAL const X509 *old_cert,
                                 OPTIONAL const EVP_PKEY *newkey);
CMP_err CMPclient_update_with_exts(CMP_CTX *ctx, CREDENTIALS **new_creds,
                                   OPTIONAL const X509 *old_cert,
                                   OPTIONAL const EVP_PKEY *newkey,
                                   OPTIONAL const X509_EXTENSIONS *exts);

/* reason codes are defined in openssl/x509v3.h */
CMP_err CMPclient_revoke(CMP_CTX *ctx, const X509 *cert, int reason);

/* get CA certs, discard duplicates, and verify they are non-expired CA certs */
CMP_err CMPclient_caCerts(CMP_CTX *ctx, STACK_OF(X509) **out);

/* get certificate request template and related key specifications */
CMP_err CMPclient_certReqTemplate(CMP_CTX *ctx,
                                  OPTIONAL OSSL_CRMF_CERTTEMPLATE **certTemplate,
                                  OSSL_CMP_ATAVS **keySpec);

/* get any root CA key update and verify it as far as possible */
CMP_err CMPclient_rootCaCert(CMP_CTX *ctx,
                             const X509 *oldWithOld, X509 **newWithNew,
                             OPTIONAL X509 **newWithOld, OPTIONAL X509 **oldWithNew);

/* get latest CRL according to cert DPN/issuer or get any update on given CRL */
CMP_err CMPclient_crlUpdate(CMP_CTX *ctx, OPTIONAL const, X509 *cert,
                            OPTIONAL const X509_CRL *last_crl, X509_CRL **crl);

/* get error information sent by the server */
char *CMPclient_snprint_PKIStatus(const OSSL_CMP_CTX *ctx, char *buf, size_t bufsize);

/* must be called between any of the above certificate management activities */
CMP_err CMPclient_reinit(CMP_CTX *ctx);

/* should be called on application termination */
void CMPclient_finish(OPTIONAL CMP_CTX *ctx);
```

```
/* CREDENTIALS helpers */
CREDENTIALS *CREDENTIALS_new(OPTIONAL const EVP_PKEY *pkey,
                             OPTIONAL const X509 *cert,
                             OPTIONAL const STACK_OF(X509) *chain,
                             OPTIONAL const char *pwd,
                             OPTIONAL const char *pwdref);
void CREDENTIALS_free(OPTIONAL CREDENTIALS *creds);

X509 *CREDENTIALS_get_cert(const CREDENTIALS *creds);
STACK_OF(X509) *CREDENTIALS_get_chain(const CREDENTIALS *creds);


/* certs is name of a file in PKCS#12 format; primary cert is of client */
/* source for private key may be "[pass:<pwd>]" or legacy "engine:<id>" */
CREDENTIALS *CREDENTIALS_load(OPTIONAL const char *certs,
                              OPTIONAL const char *key,
                              OPTIONAL const char *source,
                              OPTIONAL const char *desc /* for diagnostics */);
bool CREDENTIALS_save(const CREDENTIALS *creds,
                      OPTIONAL const char *certs, OPTIONAL const char *key,
                      OPTIONAL const char *source, OPTIONAL const char *desc);

X509 *CERT_load(const char *file, OPTIONAL const char *pass, OPTIONAL const char *desc);
bool CERT_save(const X509 *cert, const char *file, OPTIONAL const char *desc);

X509_REQ *CSR_load(const char *file, OPTIONAL const char *desc);

X509_CRL *CRL_load(const char *file, int total_timeout, OPTIONAL const char *desc);
```

```
/* LOG helpers */
bool LOG(OPTIONAL const char *func, OPTIONAL const char *file, int lineno,
         severity level, const char *fmt, ...);

bool LOG_default(OPTIONAL const char *func, OPTIONAL const char *file, int lineno,
                 severity level, const char *msg);
void LOG_set_verbosity(severity level);
void LOG_set_name(OPTIONAL const char *name);
void LOG_close(void);

/* X509_STORE helpers */
STACK_OF(X509) *CERTS_load(const char *files, OPTIONAL const char *desc,
                           int type_CA, OPTIONAL const X509_VERIFY_PARAM *s);
int CERTS_save(const STACK_OF(X509) *certs, const char *file, OPTIONAL const char *desc);
void CERTS_free(OPTIONAL STACK_OF(X509) *certs);
STACK_OF(X509_CRL) *CRLs_load(const char *file, int timeout, OPTIONAL const char *desc);
void CRLs_free(OPTIONAL STACK_OF(X509_CRL) *crls);
X509_STORE *STORE_load(const char *trusted_certs, OPTIONAL const char *desc,
                       OPTIONAL X509_VERIFY_PARAM *vpm);
bool STORE_add_crls(X509_STORE *truststore, OPTIONAL const STACK_OF(X509_CRL) *crls);
/* also sets certificate verification callback: */
bool STORE_set_parameters(X509_STORE *truststore,
                          OPTIONAL const X509_VERIFY_PARAM *vpm,
                          bool full_chain, bool try_stapling,
                          OPTIONAL const STACK_OF(X509_CRL) *crls,
                          bool use_CDP, OPTIONAL const char *cdps, int crls_timeout,
                          bool use_AIA, OPTIONAL const char *ocsp, int ocsp_timeout);
typedef X509_CRL *(*CONN_load_crl_cb_t)(OPTIONAL void *arg,
                                        OPTIONAL const char *url, int timeout,
                                        const X509 *cert, OPTIONAL const char *desc);
bool STORE_set_crl_callback(X509_STORE *store,
                            OPTIONAL CONN_load_crl_cb_t crl_cb,
                            OPTIONAL void *crl_cb_arg);
bool STORE_set1_host_ip(X509_STORE *store,
                        OPTIONAL const char *host, OPTIONAL const char *ip);
void STORE_free(OPTIONAL X509_STORE *truststore);

/* EVP_PKEY helpers */
EVP_PKEY *KEY_new(const char *spec); /* spec may be "RSA:<length>" or "EC:<curve>" */
EVP_PKEY *KEY_load(OPTIONAL const char *file, OPTIONAL const char *pass,
                   OPTIONAL const char *engine, OPTIONAL const char *desc);
void KEY_free(OPTIONAL EVP_PKEY *pkey);

/* SSL_CTX helpers for HTTPS */
SSL_CTX *TLS_new(OPTIONAL X509_STORE *truststore,
                 OPTIONAL const STACK_OF(X509) *untrusted,
                 OPTIONAL const CREDENTIALS *creds,
                 OPTIONAL const char *ciphers, int security_level);
void TLS_free(OPTIONAL SSL_CTX *tls);

/* X509_EXTENSIONS helpers */
X509_EXTENSIONS *EXTENSIONS_new(void);
/* add optionally critical Subject Alternative Names (SAN) to exts */
bool EXTENSIONS_add_SANs(X509_EXTENSIONS *exts, const char *spec);
/* add extension such as (extended) key usages, basic constraints, policies */
bool EXTENSIONS_add_ext(X509_EXTENSIONS *exts, const char *name,
                        const char *spec, OPTIONAL BIO *sections);
void EXTENSIONS_free(OPTIONAL X509_EXTENSIONS *exts);

#endif /* GENERIC_CMP_CLIENT_H */
```