Crypto API Toolkit for Intel® SGX

Developer Reference

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1. Introduction

Crypto API Toolkit for Intel® SGX Developer Reference document is for ISVs and OEMs seeking to use the SDK to harden crypto and hash operations in their applications.

1.1 Terminology

Term	Description
SGX	Intel® Software Guard Extensions
Enclave	A binary containing set of instructions that execute within SGX
PKCS	Public Key Cryptography Standards
PKCS11	Programming interface to create and manipulate cryptographic tokens
API	Application Programming Interface
ISV	Independent Software Vendor
CSP	Crypto Service Provider
PBind	Platform Binding (also referred to as sealing the data on the platform)
AES	Advanced Encryption Standard
AES-GCM	AES – Galois Counter Mode
AES-CTR	AES – Counter Mode
AES-CBC	AES – Cipher Block Chaining Mode
SHA256	Secure Hashing Algorithm 256 bits
HMAC-SHA256	Hash Message Authentication Code – SHA – 256 bits
SHA512	Secure Hashing Algorithm 512 bits
HMAC-SHA512	Hash Message Authentication Code – SHA – 512 bits
RSA	Rivest–Shamir–Adleman
PSS	Probabilistic Signature Scheme

2. Technology Overview

The Crypto API Toolkit for Intel® SGX aims at enhancing the security of ISVs' and OEMs' data protection applications by exposing enhanced and optimized interfaces that run the cryptographic operations securely within Intel® SGX. The operations are exposed and supported via PKCS11 API for Linux.

2.1 Integration Design Principles

- All the crypto operations in Crypto API Toolkit for Intel® SGX will be exposed via a set of PKCS11 provider.
- Secret keys within the enclave will never be exported in the clear.

3. Architecture Components Overview

Fig. 1 provides a high-level overview of the components and their interaction in the overall solution. Please note that this document details the implementation of Crypto API Toolkit for Intel® SGX using the PKCS11 API in Linux. For any questions/clarifications related to Windows implementation, please contact your Intel representative.

3.1 High-level Components Overview

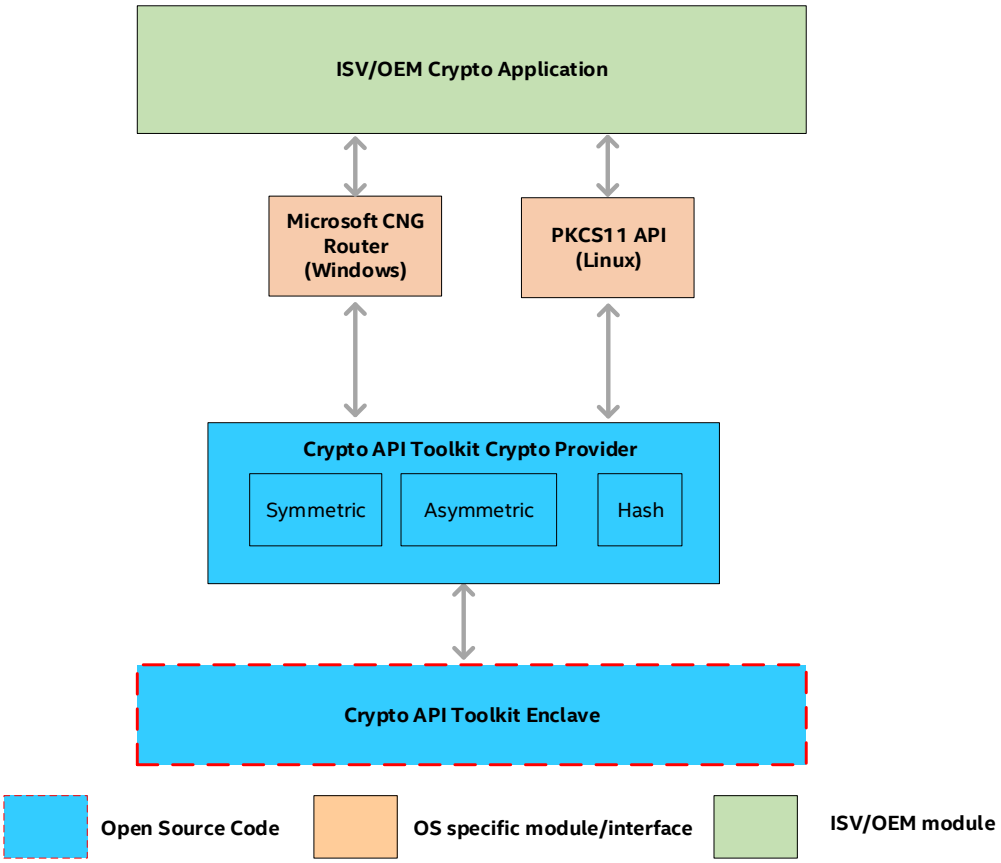

Fig. 1: High Level Architecture

- **Crypto API Toolkit Crypto Provider**: This is a PKCS11 crypto provider that exposes the symmetric, asymmetric crypto and hash functionalities of the PKCS11 specification. This component proxies calls from the application to the enclave.
- **Crypto API Toolkit Crypto Enclave**: This Crypto API Toolkit for Intel® SGX enclave implements the crypto and hash functionalities exposed by the crypto provider interface.
- The ISV/OEM components include the necessary application(s) or libraries that interact with Crypto API Toolkit for Intel® SGX through the standard PKCS11 interface.

4. Supported APIs and Mechanisms

Crypto API Toolkit for Intel® SGX implements the APIs according to PKCS v2.40 specification. In addition, Crypto API Toolkit for Intel® SGX also extends/adds additional mechanisms to the existing PKCS11 APIs to support sealing (a.k.a. platform-binding) the key and pass keys securely for HMAC operations. This document omits the next level details of the supported APIs, mechanisms and attributes. The developers are strongly encouraged to go through the PKCS11 specification for the details.

4.1 Unsupported APIs

Please refer to the PKCS v2.40 specification for details on the APIs and examples. The following is a list of PKCS11 APIs that are not supported by Crypto API Toolkit for Intel® SGX.

```
C_GetOperationState
C_SetOperationState
C_CopyObject
C_GetObjectSize
C_DigestKey
C_SignUpdate
C_SignFinal
C_SignRecoverInit
C_SignRecover
C_VerifyUpdate
C_VerifyFinal
C_VerifyRecoverInit
C_VerifyRecover
C_DigestEncryptUpdate
C_DecryptDigestUpdate
C_SignEncryptUpdate
C_DecryptVerifyUpdate
C_DeriveKey
C_SeedRandom
C_GenerateRandom
C_WaitForSlotEvent
```

4.2 Supported Algorithms

The following tables list the symmetric and asymmetric crypto algorithms, and the hash primitives supported by Crypto API Toolkit for Intel® SGX.

4.2.1.1 Symmetric Algorithms

Name	Supported modes	Supported key size in bits
Advanced Encryption Standard (AES)	CTR, GCM, CBC	128/192/256

4.2.1.2 Asymmetric Algorithms

Name	Supported modes	Supported key size in bits
RSA	Includes RSA algorithms that use PKCS1, Optimal Asymmetric Encryption Padding (OAEP) encoding or padding, or Probabilistic Signature Scheme (PSS) plaintext padding	1024/2048/3072/4096

4.2.1.3 Hashing Algorithms

Name	Notes
Secure Hash Algorithm 256 (SHA256)	Includes HMAC-SHA256
Secure Hash Algorithm 512 (SHA512)	Includes HMAC-SHA512

Note:

- Crypto API Toolkit for Intel® SGX supports a maximum of 64 keys each for symmetric and asymmetric. This can be modified in the code according to the ISV/OEM requirement provided there is enough memory for the enclave to run.
- For AES-CTR and AES-CBC modes of operation, Crypto API Toolkit for Intel® SGX restricts the support to only 16-byte IV values.
- For AES-GCM, Crypto API Toolkit for Intel® SGX restricts the tag size to 12 to 16 bytes.

4.3 Supported Mechanisms

As mentioned in the previous section, Crypto API Toolkit for Intel® SGX performs the supported symmetric, asymmetric and hash operations via the following mechanisms:

Mechanism	Operation
`CKM_AES_KEY_GEN`	Generate an AES key
`CKM_AES_CTR`	AES crypto operations (including wrap and unwrap) with CTR

CKM_AES_GCM	AES crypto operations (including wrap and unwrap) with GCM
CKM_AES_CBC	AES crypto operations (including wrap and unwrap) with CBC
CKM_AES_CBC_PAD	AES crypto operations (including wrap and unwrap) with CBC padded
CKM_RSA_PKCS_KEY_PAIR_GEN	Generate an RSA keypair
CKM_RSA_PKCS	Asymmetric (RSA) crypto, wrap/unwrap (OAEP padding) & sign/verify operations with PKCS1 padding
CKM_RSA_PKCS_PSS	Asymmetric (RSA) sign/verify operations with PSS padding with salt size of 32 bytes and SHA25 digest.
CKM_SHA256_RSA_PKCS	Asymmetric (RSA) signHash/verify operations with PKCS1 padding. The source buffer is hashed using SHA256 and the hash is signed.
CKM_SHA512_RSA_PKCS	Asymmetric (RSA) signHash/verify operations with PKCS1 padding. The source buffer is hashed using SHA512 and the hash is signed.
CKM_SHA256_RSA_PKCS_PSS	Asymmetric (RSA) signHash/verify operations with PSS padding with salt size of 32 bytes and SHA25 digest. The source buffer is hashed using SHA256 and the hash is signed.
CKM_SHA512_RSA_PKCS_PSS	Asymmetric (RSA) signHash/verify operations with PSS padding with salt size of 32 bytes and SHA25 digest. The source buffer is hashed using SHA512 and the hash is signed.
CKM_AES_PBIND	Platform binding (sealing & unsealing) operations on AES keys.
CKM_RSA_PBIND_EXPORT/ CKM_RSA_PBIND_IMPORT	Platform binding (sealing & unsealing) operations on an RSA keys.
CKM_SHA256	Hashing with SHA256
CKM_SHA512	Hashing with SHA512
CKM_SHA256_HMAC_AES_KEYID	HMAC with SHA256
CKM_SHA512_HMAC_AES_KEYID	HMAC with SHA512
CKM_EXPORT_RSA_PUBLIC_KEY	Exporting an asymmetric public key
CKM_IMPORT_RSA_PUBLIC_KEY	Importing an asymmetric public key
CKM_EXPORT_QUOTE_RSA_PUBLIC_KEY	Exporting an asymmetric public key along with public key hash and quote.

The custom mechanisms that are implemented by Crypto API Toolkit for Intel® SGX are described below:

4.3.1 CKM_AES_PBIND

Crypto API Toolkit for Intel® SGX exposes a mechanism CKM_AES_PBIND to wrap an AES key created inside the enclave to be platform bound (sealed) so that it can be unwrapped (imported) and used later. The operation to wrap an AES key using platform binding mechanism is explained in the section Sealing (platform binding) and unsealing the key

4.3.2 CKM_RSA_PBIND_EXPORT & CKM_RSA_PBIND_IMPORT

Platform binding or sealing is the operation where the data is encrypted with the platform key that is specific to the platform and not exposed outside. Crypto API Toolkit for Intel® SGX exposes a mechanism CKM_RSA_PBIND_EXPORT to wrap a RSA key created inside the enclave to be platform bound (sealed) so that it can be unwrapped (imported) and used later. The platform bound blob will either have only the

public key, or the key pair based on how the key was generated or imported. The operation to wrap a RSA key using platform binding mechanism is explained in the section Sealing (platform binding) and unsealing the key

4.3.3 CKM_SHA256_HMAC_AES_KEYID

Crypto API Toolkit for Intel® SGX exposes the mechanism `CKM_SHA256_HMAC_AES_KEYID` for SHA256 HMAC operations. With this mechanism, the application can specify the key handle that it wants to use for doing the HMAC operation without the need to pass the key in the clear. The details of the mechanism are explained in the section Message digesting and HMAC Operations

4.3.4 CKM_SHA512_HMAC_AES_KEYID

Crypto API Toolkit for Intel® SGX exposes the mechanism `CKM_SHA512_HMAC_AES_KEYID` for SHA512 HMAC operations. With this mechanism, the application can specify the key handle that it wants to use for doing the HMAC operation without the need to pass the key in the clear. The details of the mechanism are explained in the section Message digesting and HMAC Operations

4.3.5 CKM_EXPORT_QUOTE_RSA_PUBLIC_KEY

Crypto API Toolkit for Intel® SGX can export the public key along with hash and a quote based on that using the mechanism `CKM_EXPORT_QUOTE_RSA_PUBLIC_KEY`. The details are explained in the section Export the public portion of an asymmetric key along with a quote and hash

4.4 Supported Attributes

Crypto API Toolkit for Intel® SGX supports the following attributes:

CKA_CLASS	CKA_KEY_TYPE
CKA_PRIVATE	CKA_SIGN
CKA_TOKEN	CKA_VERIFY
CKA_ENCRYPT	CKA_MODIFIABLE
CKA_DECRYPT	CKA_COPYABLE
CKA_WRAP	CKA_DERIVE
CKA_UNWRAP	CKA_LOCAL
CKA_MODULUS_BITS	CKA_LABEL
CKA_VALUE_LEN	CKA_VALUE_KEY_BUFFER
CKA_ID	CKA_LABEL
CKA_KEY_GEN_MECHANISM	

4.4.1 Mandatory attributes to be set for key generation

Attribute	Key
CKA_CLASS	AES, RSA
CKA_KEY_TYPE	AES, RSA
CKA_MODULUS_BITS	RSA (public key)
CKA_VALUE_LEN	AES
CKA_VALUE_KEY_BUFFER	AES (Raw key import)

4.4.2 Limitations and Restrictions

Attribute	Information
CKA_DERIVE	Since Crypto API toolkit does not support key derivation, CKA_DERIVE cannot be set to CK_TRUE. Default value is CK_FALSE.
CKA_COPYABLE	Since Crypto API toolkit does not support copying objects, CKA_COPYABLE cannot be set to CK_TRUE. Default value is CK_FALSE.

5. Flows

Crypto API Toolkit for Intel® SGX provider layer depends on the SGX enclave for performing key generation, crypto and hash operations. The enclave module depends on Intel® Software Guard Extensions SSL library (a.k.a. SGX-SSL - OpenSSL built for SGX) for crypto functionalities (except AES-CTR) and Intel® IPP Cryptography library for hash/digest/HMAC and AES-CTR operations.

5.1 Typical Flow

In a typical flow, the application will,

1. Load the Crypto API Toolkit for Intel® SGX dynamic library (or link to the dynamic library and can optionally perform steps 2 & 3).
2. Get the pointer to the function list via C_GetFunctionList.
3. Load the function list.
4. Call C_Finalize to complete any previous sessions, if required.
5. Call C_Initialize to initialize the PKCS11 library.
6. The application can enumerate the slots and get info about the token using C_GetSlotList and C_GetTokenInfo.
7. If the token has not been initialized, the application will initialize the token using C_InitToken and get info of the slot using C_GetSlotInfo.
8. The application can get the list of mechanisms supported and the information of those mechanisms by using C_GetMechanismList and C_GetMechanismInfo
9. Open session(s) to interact with the token. The application might need to initialize PIN, set PIN and login based on the operations to be performed.
10. Perform crypto including key[pair] generation, encrypt/decrypt, wrap/unwrap keys, sign/verify and hash/digest/HMAC operations.
11. Perform cleanup operations (destroying or wrapping the keys for usage later, freeing up memory etc.,)
12. Close the session(s).
13. Finalize the provider.
14. Unload the library.

Please refer to the PKCS v2.40 specification for details on the APIs and examples for the various operations. The below sections explain the operations with custom/additional mechanisms that Crypto API Toolkit for Intel® SGX implements.

5.2 Wrapping and Unwrapping Keys

The keys created inside the Crypto API Toolkit for Intel® SGX enclave can be wrapped and persisted. For the purpose of this discussion, the terms ***wrap and export*** will be used interchangeably as well as the

terms ***unwrap and import***. The wrapped keys can be used in the same session or later (if persisted) by importing the exported key blob. Crypto API Toolkit for Intel® SGX does not export the keys without wrapping them or binding them to the platform (no secret key export). PKCS11 specification talks in detail about wrapping and unwrapping the keys. Crypto API Toolkit for Intel® SGX assures that the keys can get unwrapped only inside the enclave and does not come out in the clear.

IMPORTANT

The following restrictions are imposed by Crypto API Toolkit for Intel® SGX for the wrapping and wrapped keys.

1. A wrapped key can get unwrapped only inside the enclave. It cannot be extracted to come out in the clear.
2. A key used for wrapping cannot be used for encryption or decryption.
3. If the key that is used for wrapping another key, was used for encrypting data earlier, that encrypted data cannot be decrypted post the wrapping operation.

5.2.1 Sealing (platform binding) and unsealing the key

By sealing and exporting the key as platform bound, the application can ensure that the exported key *cannot* be imported into another platform (system/machine) since the key used for sealing/platform binding is system/machine specific. This section details the steps involved in exporting a key as platform bound and then importing the sealed key back into the enclave.

5.2.1.1 Wrapping a key as platform bound (sealing the key)

A key can be wrapped and exported from the enclave either as platform bound or wrapped with another key by performing the steps below:

- The application initializes the PKCS11 library and the token.
- The application opens the session with the PKCS11 library and generates the key to be wrapped as platform bound (or it already has a handle to the key that is in the enclave).
- The application calls `C_WrapKey` with `CKM_AES_PBIND` or `CKM_RSA_PBIND_EXPORT` as `CKM_MECHANISM_TYPE` and a `NULL_PTR` for `hWrappingKey` and `pWrappedKey`.
- If the key that is pointed to by `hKey` is valid, Crypto API Toolkit for Intel® SGX calculates the size of the buffer to hold the sealed key and returns back the buffer size via `pulWrappedKeyLen` parameter.
- If the call is successful, the application allocates the buffer as per the returned buffer size.
- The application calls `C_WrapKey` with the same parameters, but this time with the allocated buffer for `pWrappedKey` parameter and the allocated size in `pulWrappedKeyLen`.
- The Crypto API Toolkit for Intel® SGX enclave seals the key and returns it in the `pWrappedKey` buffer. For the asymmetric keys, both the public and private keys are bound together (if the key pair is generated inside the enclave, or only the public key if the public key alone was imported/unwrapped earlier).

5.2.1.2 Unwrapping a platform bound (sealed) key into the enclave

The previously exported platform bound key can be imported to the same platform and reused by following the steps below:

- The application initializes the PKCS11 library and the token.
- The application opens the session with the PKCS11 library.
- ***Symmetric (AES) keys***: The application calls `C_UnwrapKey` with `CKM_AES_PBIND` as `CKM_MECHANISM_TYPE` and the attributes required for the key being unwrapped, along with the buffer containing the wrapped key and its size. The unwrapping key handle (`hUnwrappingKey`) is set to `NULL_PTR`. The application also passes an object handle which will contain the handle to the key that was unwrapped and imported inside the enclave.
- If the unwrap operation is successful, the application will receive the key handle to the unwrapped key.
- ***Asymmetric (RSA) keys:*** PKCS11 specification does not specify a mechanism for importing a sealed asymmetric keypair blob. The `C_UnwrapKey` API cannot be used to get both public and private key handles if the platform bound blob contains the keypair. To overcome this limitation, Crypto API Toolkit for Intel® SGX, introduces a mechanism `CKM_RSA_PBIND_IMPORT` to be used with `C_GenerateKeyPair` API.
    - Crypto API Toolkit for Intel® SGX adds a structure `CK_RSA_PBIND_IMPORT_PARAMS` for this purpose.

```
typedef struct CK_RSA_PBIND_IMPORT_PARAMS {
    CK_BYTE_PTR   pPlatformBoundKey;        // pointer to pbind blob
    CK_ULONG      ulPlatformBoundKeyLen;    // size of the blob
};
```

    - The application fills the member `pPlatformBoundKey` with the pointer to application allocated memory containing the platform bound blob. It also sets the size of the blob in `ulPlatformBoundKeyLen`.
    - The application, then calls `C_GenerateKeyPair` with the mechanism type set to `CKM_RSA_PBIND_IMPORT` and the mechanism filled as above. The application also needs to set the corresponding attributes for the public (and private if present in the blob) key that is being imported.
    - If the unsealing is successful, Crypto API Toolkit for Intel® SGX returns the key handles for the public and private keys that are imported inside the enclave. (If the platform bound blob contained only the public key, the private key handle will be `NULL_PTR`).

5.2.2 Wrapping and unwrapping a symmetric key

An application can do a custom wrapping and export the key (for example, the application might want to store the symmetric key by wrapping it with a symmetric key or an asymmetric key).

5.2.2.1 Wrapping a symmetric key with symmetric or asymmetric key

After performing the initialization (load library, initialize and init token) and after creating the keys (the key used for wrapping and the key to be wrapped), the application,

1. Sets the mechanism parameters based on the symmetric mode to be used (CTR, GCM or CBC) or asymmetric key. Below are the mechanisms and the parameters.

AES-CTR	`typedef struct CK_AES_CTR_PARAMS {`
	`  CK_ULONG ulCounterBits;`
	`  CK_BYTE cb[16];`
	`} CK_AES_CTR_PARAMS;`

AES-GCM	`typedef struct CK_GCM_PARAMS {`
	`  CK_BYTE_PTR  pIv;`
	`  CK_ULONG  ulIvLen;`
	`  CK_ULONG  ulIvBits;`
	`  CK_BYTE_PTR  pAAD;`
	`  CK_ULONG  ulAADLen;`
	`  CK_ULONG  ulTagBits;`
	`} CK_GCM_PARAMS;`

2. The application fills the structure and passes the address of the structure to the pParameter of `CK_MECHANISM`. It also fills the `ulParameterLen` to the size of the structure (For AES-CBC, it is only the IV which is directly filled as byte array and the size of the array is passed for ulParameterLen, and for wrapping using an asymmetric key, there are no parameters)
3. The application calls `C_WrapKey` with the mechanism, the object handles of the key to be wrapped and key to be used for wrapping and passes a `NULL_PTR` for the destination buffer.
4. If the key handles are valid, the enclave returns the size of the destination buffer required to hold the wrapped key.
5. If the call is successful, the application allocates the buffer as per the returned buffer size.
6. The application calls `C_WrapKey` with the same parameters, but with the allocated buffer for `pWrappedKey` parameter and the allocated size in `pulWrappedKeyLen`.
7. Crypto API Toolkit for Intel® SGX wraps the key and returns it in the `pWrappedKey` buffer.

5.2.2.2 Unwrapping a symmetric key with symmetric or asymmetric key

After performing the initialization (load library, initialize and init token) and after creating the keys (the key used for wrapping and the key to be wrapped), the application

1. Sets the mechanism parameters based on the symmetric mode to be used (CTR, GCM or CBC) or asymmetric key. The mechanisms and the parameters are as listed in 5.2.2.1.
2. The application fills the structure and passes the address of the structure to the pParameter of `CK_MECHANISM`. It also fills the ulParameterLen to the size of the structure (For AES-CBC, it is only the IV which is directly filled as byte array and the size of the array is passed for ulParameterLen, and for wrapping using an asymmetric key, there are no parameters)
3. The application calls `C_UnwrapKey` with the mechanism, the object handle of key to be used for wrapping, the wrapped key buffer and its length along with the key attributes to be set (in the `pTemplate` parameter) on the key being unwrapped.

4. If the key handle is valid and unwrapping is successful, the enclave returns the unwrapped key handle in the phKey parameter. The key is unwrapped (imported) inside the Crypto API Toolkit for Intel® SGX enclave and never is visible outside of it.
5. The application can then start using this key handle for the purposes set in the template that is sent during the call to unwrap.

5.2.3 Wrapping and unwrapping an asymmetric key

For asymmetric keys, both public and private keys can be exported (wrapped) as platform bind as explained in the section above. The application might want to export the public key portion only (for example, verification of signature). The application might want to export the public key along with a quote from the enclave to verify the trust worthiness of the enclave as well as to provision a secret. Both these operations are explained below:

5.2.3.1 Export the public portion of an asymmetric key

After performing the initialization (load library, initialize and opening the session) and after creating the key pair (whose public key is to be exported), the application

1. Sets the mechanism to CKM_EXPORT_RSA_PUBLIC_KEY.
2. The application calls C_WrapKey with the mechanism, the object handle of the key whose public portion is to be exported and passes a NULL_PTR for the hWrappingKey and the destination buffer.
3. If the key handle is valid, the enclave returns the size of the destination buffer required to hold the exported public key which is the total size of the actual public key buffer (modulus and exponent) and sizeof(CK_RSA_PUBLIC_KEY_PARAMS).
4. If the call is successful, the application allocates the buffer as per the returned buffer size.
5. The application calls C_WrapKey with the same parameters, with the allocated buffer for pWrappedKey parameter and the allocated size in pulWrappedKeyLen.
6. The Crypto API Toolkit for Intel® SGX enclave exports the public key and returns it in the pWrappedKey buffer (below format).

Size	CK_RSA_PUBLIC_KEY_PARAMS		ulModulusLen	ulExponentLen
Data	ulExponentLen	ulModulusLen	modulus	exponent

5.2.3.2 Export the public portion of an asymmetric key along with a quote and hash

After performing the initialization (load library, initialize and opening the session) and after creating the key pair (whose public key is to be exported along with the enclave quote), the application

1. Sets the mechanism to CKM_EXPORT_QUOTE_RSA_PUBLIC_KEY and fills the mechanism parameters in the structure CK_QUOTE_RSA_PUBLIC_KEY_PARAMS.

```
typedef struct CK_QUOTE_RSA_PUBLIC_KEY_PARAMS {
    CK_BYTE_PTR       pSpid;               // pointer to SPID
    CK_ULONG          ulSpidLen;           // length of SPID in bytes
    CK_BYTE_PTR       pSigRL;              // pointer to SIGRL
    CK_ULONG          ulSigRLLen;          // length of SIGRL in bytes
    CK_ULONG          ulQuoteSignatureType; // linked or unlinked
};
```

2. The application calls `C_WrapKey` with the mechanism details, the object handles of the key to be exported and passes a `NULL_PTR` for the `hWrappingKey` and destination buffer.
3. If the key handle is valid, the enclave returns the size of the destination buffer required to hold the exported public key and quote which is the total size of the actual public key buffer and `sizeof(CK_RSA_PUBLIC_KEY_PARAMS)` and the size of the quote itself. The quote is of the format `sgx_quote_t` and contains the hash of the public key and the quote generated based on this.
4. If the call is successful, the application allocates the buffer as per the returned buffer size.
5. The application calls `C_WrapKey` with the same parameters, with the allocated buffer for `pWrappedKey` parameter and the allocated size in `pulWrappedKeyLen`.
6. The Crypto API Toolkit for Intel® SGX enclave calculates the hash of the public key, generates a quote based on this as well as the other parameters passed (SPID, SIGRL etc.,) and returns it in the `pWrappedKey` buffer (below format).

Size	CK_RSA_PUBLIC_KEY_PARAMS		ulModulusLen	ulExponentLen	sgx_quote_t	
Data	ulExponentLen	ulModulusLen	modulus	exponent	SHA256 hash of the public key	quote

The following example shows how the quote from the enclave based on the public key's hash can be retrieved.

```
std::vector<CK_BYTE> customQuote(CK_MECHANISM_TYPE     mechanismType,
                                 CK_SESSION_HANDLE     hSession,
                                 CK_OBJECT_HANDLE      hKey)
{
    CK_RV                   p11Status          = CKR_GENERAL_ERROR;
    CK_MECHANISM            mechanism          = { mechanismType, NULL_PTR, 0 };
    CK_ULONG                quotePublicKeyLen  = 0UL;
    CK_ULONG                signatureType      = UNLINKABLE_SIGNATURE;
    bool                    result             = false;
    std::vector<CK_BYTE>    spid { 0x11, 0x22, 0x33, 0x44, 0x55, 0x66, 0x77, 0x88, \
                                   0x99, 0x99, 0x88, 0x77, 0x66, 0x55, 0x44, 0x33 };
    std::vector<CK_BYTE>    sigRL;
    std::vector<CK_BYTE>    quotePublicKey;
    CK_MECHANISM_PTR        pMechanism((CK_MECHANISM_PTR)&mechanism);

    CK_QUOTE_RSA_PUBLIC_KEY_PARAMS quoteRSAParams =
    {
        spid.data(),
        spid.size(),
        sigRL.data(),
        sigRL.size(),
        signatureType
    };

    do
    {
        pMechanism->pParameter = &quoteRSAParams;
        pMechanism->ulParameterLen = sizeof(quoteRSAParams);
```

```
        p11Status = p11->C_WrapKey(hSession,
                                   pMechanism,
                                   NULL_PTR,
                                   hKey,
                                   NULL_PTR,
                                   &quotePublicKeyLen);
        if (CKR_OK != p11Status)
        {
            break;
        }

        quotePublicKey.resize(quotePublicKeyLen);
        p11Status = p11->C_WrapKey(hSession,
                                   pMechanism,
                                   NULL_PTR,
                                   hKey,
                                   quotePublicKey.data(),
                                   &quotePublicKeyLen);
        if (CKR_OK != p11Status)
        {
            break;
        }

        result = true;
    } while (false);

    if (!result)
    {
       quotePublicKey.clear();
    }

    return quotePublicKey;
}
```

The quote portion of this blob can be verified with the Intel Attestation Server using remote attestation. Please refer to https://github.com/intel/sgx-ra-sample for how to verify the quote. Please also refer to https://software.intel.com/en-us/articles/code-sample-intel-software-guard-extensions-remote-attestation-end-to-end-example for more details.

Once the quote verification is successful, the verification module can compute the SHA256 hash of the public key (present in the blob as shown above) and compare against the SHA256 hash in the blob. This public key may be used to provision a secret key into the enclave.

5.2.3.3 Import the public portion of an asymmetric key

The application after creating the RSA key pair (whose public key is to be exported), can perform the steps below to export the public portion of the RSA key that it has created.

1. Sets the mechanism to `CKM_IMPORT_RSA_PUBLIC_KEY`.
2. The application calls `C_UnwrapKey` with the mechanism, the public key buffer (in the format as mentioned above) and its length along with the key attributes to be set (in the `pTemplate` parameter) on the key being imported. The key handle to be used for unwrapping is set to `NULL_PTR`.
3. If the import is successful, the enclave returns the key handle for the imported public key in the phKey parameter.
4. The application can then start using this key handle for the purposes set in the template that is sent during the call to unwrap.

5.3 Message digesting and HMAC Operations

Crypto API Toolkit for Intel® SGX supports hashing/digesting of the message. The detailed flow to generate a message digest are explained in detail with example in PKCS11 v2.40 specification. In this section we will explain how to generate a digest with HMAC using the secret key (AES) already generated or present in the enclave.

After performing the initialization, the application generates or imports the symmetric key (AES) to be used for HMAC operation. The application then,

1. Sets the mechanism to `CKM_SHA256_HMAC_AES_KEYID` or `CKM_SHA512_HMAC_AES_KEYID`, based on the requirement.
2. Sets the `ulKeyID` parameter of the `CK_HMAC_AES_KEYID_PARAMS` to the AES key to be used for HMAC operation. This `ulKeyID` is the AES key handle that has been generated or imported earlier. The `pMechanism`'s `pParameter` is set to point to this structure and its `ulParameterLen` is set to `sizeof(CK_HMAC_AES_KEYID_PARAMS)`.
3. Calls `C_DigestInit` with this `pMechanism` followed by `C_DigestUpdate`.
4. Makes a call to `C_DigestFinal` with `NULL_PTR` for `pDigest`. The enclave will calculate the size of the buffer to hold the digest and return it via `pulDigestLen`.
5. The application allocates the memory for the buffer and calls `C_DigestFinal` with this buffer to get the message digest.

5.4 Asymmetric Sign and Verify

Crypto API Toolkit for Intel®SGX supports signing and verify data using an asymmetric key pair.
The flows supported are C_SignInit → C_Sign and C_VerifyInit → C_Verify. C_SignFinal and C_VerifyFinal are not supported.

The following mechanisms are supported for signing and verifying data.

Mechanism	**Description**
CKM_RSA_PKCS	Signs a data buffer.
CKM_RSA_PKCS_PSS	Signs a data buffer.
CKM_SHA256_RSA_PKCS	Hashes the data buffer and then signs. Uses SHA256 for hash computation.
CKM_SHA512_RSA_PKCS	Hashes the data buffer and then signs. Uses SHA512 for hash computation.
CKM_SHA256_RSA_PKCS_PSS	Hashes the data buffer and then signs. Uses SHA256 for hash computation. PSS padding scheme uses SHA256 digest.
CKM_SHA512_RSA_PKCS_PSS	Hashes the data buffer and then signs. Uses SHA512 for hash computation. Please note that the PSS padding scheme supports only SHA256 digest.

5.5 Power Transition Scenarios

Crypto API Toolkit for Intel® SGX does not explicitly save/restore keys, handles, or crypto contexts during power transition scenarios like sleep, hibernate and resume. It is the application's responsibility to intercept the power events and handle them by closing the key(s) and session(s) and re-establishing the session on a resume. The application can also wrap or platform bind the keys every time they are created or imported, and save it on to the disk.

6. Building the source

The source has been built and tested with CentOS 7.5, Ubuntu Desktop v16.04 and v18.04.

6.1 Pre-requisites

Crypto API Toolkit for Intel® SGX depends on

6.1.1 autotools (autoconf, automake, libtool)

On CentOS, autotools can be installed with the command

```
sudo yum install autotools-latest
```

On Ubuntu, autotools can be installed with the command

```
sudo apt-get install autoconf automake libtool
```

6.1.2 g++ compiler with C++11 support

6.1.3 Intel® SGX SDK for Linux.

- The latest Intel(R) SGX SDK can be installed from https://01.org/intel-software-guard-extensions/downloads for the operating systems supported.
- Install the driver, libsgx-enclave-common and SDK in that order.
- Please refer to Intel® Software Guard Extensions (Intel® SGX) SDK for Linux* OS Installation Guide for more details.

6.1.4 Intel® SGX SSL add-on

- Please download the Intel(R) SGX SSL from https://github.com/intel/intel-sgx-ssl, follow the instructions there to install it. Please note that the current release of Crypto API Toolkit for Intel(R) SGX has been validated with Intel(R) SGX SSL that uses OpenSSL version 1.1.1a.
- The build scripts have been configured to build with the release versions of SGX SSL libraries.

6.2 Enclave configuration

6.2.1 HeapMaxSize

The enclave configuration XML is configured for 80MB as `HeapMaxSize`. The ISVs/OEMs should review this configuration file setting to make sure it satisfies their requeirements. For example, AES-GCM multipart decrypt requires the enclave to store the decrypted buffer internally until C_DecryptFinal is called. When the multipart decrypted buffer grows beyond the available size (`HeapMaxSize`), the enclave will fail (crash). This maximum heap size includes the tag outputted in case of AES-GCM and the padding in case of AES-CBC.

6.2.2 Multithreaded support

By default, the enclave is configured to not support multithreaded applications. This can be changed by updating the `TCSNum` tag in the enclave configuration XML. The enclave support for threads is limited by the number of TCSs and the available EPC memory. The maximum number of threads that an enclave can run simultaneously inside the enclave is the same as the number of logical processors in the system. This is typically the value set in the `TCSNum` tag.

6.2.3 Build configuration

The enclave is configured to have **`DisableDebug`** set to 0 for the purpose of debug during development and integration. This means that enclave will be debuggable. The ISVs/OEMs must configure this tag `<DisableDebug>` to 1 for a production enclave. Please refer to the section **Enclave Project Configurations** in the Intel® Software Guard Extensions SDK for Linux* OS – Developer Reference for more information. Please also note that the provider that loads the enclave needs to be built with NDEBUG preprocessor macro that disables the SGX_DEBUG_FLAG (will be defined as 0).

NOTE The release binaries thus built will need to be signed with a whitelisted key for the enclave to load and function properly. The details for signing and whitelisting the enclave is presented in section 7.5 Signing and Whitelisting the Enclave

6.3 Build Steps

The enclave, the provider and the sample application are configured to be built with autotools.

The sequence of steps to build are below:

6.3.1 Configure

```
sh autogen.sh
./configure
```

The build can be configured using the following additional options.

Option	Description
`--prefix=/path-to-install/`	Sets the installation directory. Defaults to */usr/local/* if this option is not specified.
`--with-toolkit-path=/path-for-tokens/`	Sets the location for tokens to be created. Defaults to */opt/intel/cryptoapitoolkit/* if this option is not specified.
`--with-sgxsdk=/path-to-sgxsdk-installation/`	The SGX SDK installation directory. Defaults to */opt/intel/sgxsdk/* if this option is not specified.
`--with-sgxssl=/path-to-sgxssl-installation/`	The SGX SSL installation directory. Defaults to */opt/intel/sgxssl/* if this option is not specified.

`--enable-import-raw-symkey-support= "yes"`	Setting this option to 'yes' allows importing a data buffer (raw key import) into Crypto API Toolkit.
`--enable-import-raw-symkey-support-for-hmac="yes"`	Setting this option to 'yes' allows the use of raw key imported as the secret buffer for HMAC operations.

6.3.2 Build and Install

To build the Crypto API Toolkit for Intel® SGX, please run

```
sudo make
```

To install Crypto API Toolkit for Intel® SGX, please run

```
sudo make install
```

IMPORTANT

- ISVs/OEMs need to carefully evaluate their requirements, mainly from a security standpoint, and decide whether they require the support for importing raw key using `--enable-import-raw-symkey-support`
- Please note that the enclave is signed with a test signing key. A production enclave should go through the process of signing and whitelisting an enclave as explained in the next section.

6.4 Signing and Whitelisting the Enclave

For deploying the enclave for production, the unsigned enclave DLL needs to go through production signing and whitelisting process. The process of signing the enclave is detailed in Intel SGX Developer Reference for Linux. The process of whitelisting and onboarding is detailed in https://software.intel.com/en-us/articles/intel-software-guard-extensions-product-licensing-faq.

Once the enclave is signed and whitelisted, Intel Developer Services will send/notify the submitted about the completion of whitelisting process and the updated whitelisted enclave bin (for Linux) can be downloaded from http://whitelist.trustedservices.intel.com/SGX/LCWL/Linux/sgx_white_list_cert.bin.

Once the enclave is whitelisted and the updated whitelist cert bin is available in the link above, the AESM service, when it starts and connected to the network will fetch it, after a reboot. The enclave load call (`sgx_create_enclave`) for the production signed enclave will fail with `sgx_status_t::SGX_ERROR_SERVICE_INVALID_PRIVILEGE`, if the AESM has not downloaded the updated whitelist cert binary. This can be handled by building the provider with the whitelist cert bin and manually registering the cert chain by using the SGX API `sgx_register_wl_cert_chain`.