SKS (Secure Key Store) API and Architecture

Note: This is an early version of a system in development. That is, the specification is incomplete and may also change considerably before finalization. However, it might give you a fairly good idea about the "air-tight" provisioning concept.

Feedback is encouraged!

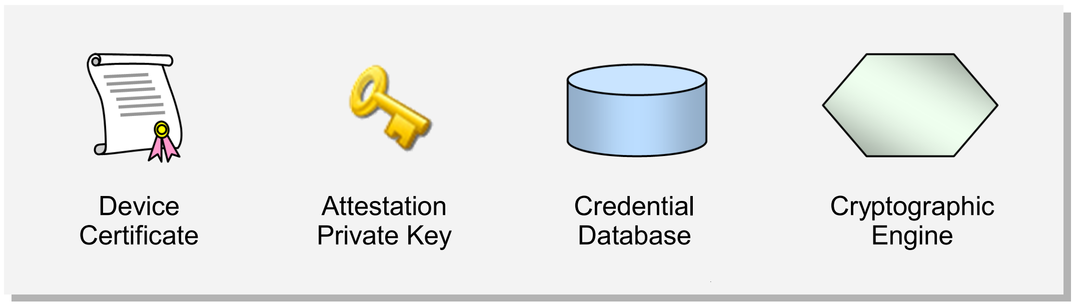
Table of Contents

Introduction

This document describes the API (Application Programming Interface) and architecture of a system called SKS (Secure Key Store). SKS is essentially an enhanced smart card that is optimized for on-line provisioning of cryptographic keys and associated attributes.

Architecture

Below is a picture showing the components in the SKS architecture:



All operations inside of an SKS are supposed to be protected from tampering by malicious external entities but the degree of internal protection may vary depending on the environment that the SKS is running in. That is, an SKS housed in a smart card which may be inserted in an arbitrary computer must keep all data within its protected memory, while an SKS that is an integral part of a mobile phone processor may store credential data in the same external Flash where programs are stored, but sealed by an SKS-resident “master key”.

The *Device Certificate* and its associated *Attestation Private Key* form the foundation for the mechanism that secure provisioning of keys, which remains secure even if the surrounding middleware (for *self-contained* SKSes NB) and network are unsecured.

The *Cryptographic Engine* performs in addition to standard cryptographic operations on private and secret keys, the core of the provisioning operations which from an API point-of-view are considerably more complex than the former.

A vital part of the *Cryptographic Engine* is a high quality random number generator since the integrity of the entire provisioning scheme is relying on this.

The *Credential Database* holds keys and other data that is related to keys such as protection and extension objects.

Provisioning API

Although SKS may be regarded as a “component”, it actually comprises of three associated systems: The KeyGen2 protocol, the SKS architecture, and the provisioning API described in this document. *These items are tightly be matched* in order to create a secure and interoperable system. A question that arises is of course how compatible this scheme is with respect to current protocols, APIs, and smart cards. The simple answer is: NOT.

A reason why SKS still makes sense is that few of the current protocols, APIs and smart cards support secure on-line provisioning to end-users because *the current generation of smart cards are almost exclusively personalized by more or less proprietary software used by specific card administrators or by automated production facilities*. It is evident that (at least) mobile phones need a scheme that is more consistent with the on-line paradigm since SIM-cards due to operator-bindings do not scale particularly well. *“On the internet anybody can be an operator of something”*.

“Key User” API

In this document Key User API refers to operations that are used by security applications like SSL-client-certificate authentication, S/MIME, and Kerberos (PKINIT). The Key User API is not a core SKS facility but its implementation is anyway RECOMMENDED, particularly for SKSes that are featured in connectable containers such as smart cards since card middleware have proved to be a major stumbling block for wide-spread adoption of PKI cards for consumers.

The described Key User API is fully mappable to the subset of CryptoAPI, PKCS#11, and JCE that most existing PKI-using applications rely on.

The standard Key User API does not rely on authenticated sessions like featured in TPM 1.2 because this is a *local security option*, while the provisioning API has its own self-contained (mandatory) authentication scheme.

If another Key User API is used the only requirement is that the key objects created by the provisioning API, are compatible with the former.

Objects

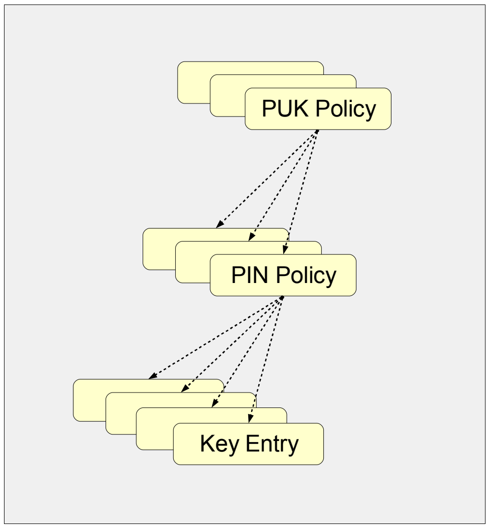
The SKS API (as well as its companion protocol KeyGen2), assumes that objects are arranged in a specific fashion in order to work. At the core of the system are the cryptographic keys which are not only used for authentication, signing etc. but also for key life-cycle management and management of key attributes.

All provisioned keys, included symmetric dittos, are identified and managed through an X.509 certificate. The reason for this arrangement is that this facilitates *universal object management* as well as supporting the POI (Proof Of Issuance) concept for enabling *secure remote object management by independent issuers*.

Note: unlike 7816-compatible smart cards, SKS has no visible file system, only objects.

Key Protection Objects

Keys may optionally be protected by PIN-codes. Each PIN-protected key have a separate error-counter, but a single PIN policy object may govern multiple keys. A PIN-policy and its associated keys may in turn be governed by a PUK (Personal Unlock Key) policy object that can be used to reset error-counters that have passed the limit as defined by the PIN policy.



PIN and PUK policy objects are not directly addressable after provisioning; in order to read PIN and/or PUK policy data, you need to use an associated key handle as input.

The following XML extract shows a matching key generation (provisioning) request in KeyGen2:

```
<CreateObject>
   <PUKPolicy ID="PUK.1" Format="numeric" RetryLimit="3" EncryptedValue="mjRKrcuO ... 1O/e9mgMf3qw">
      <PINPolicy ID="PIN.1" Format="numeric" Grouping="shared" MaxLength="8" MinLength="4"
                 PatternRestrictions="three-in-a-row sequence" RetryLimit="3">
         <KeyPair ID="Key.1" KeyUsage="encryption">
            <RSA KeySize="1024"/>
         </KeyPair>
         <KeyPair ID="Key.2" KeyUsage="authentication">
            <RSA KeySize="2048"/>
         </KeyPair>
      </PINPolicy>
   </PUKPolicy>
</CreateObject>
```

This sequence should be interpreted as a request for two RSA keys to be generated, protected by user-defined (within specified policy limits) PINs (the same for both keys), where the PINs are governed by an issuer-defined, and (protocol-wise) secret PUK.

Key Data Objects

Provisioned keys always have an associated X.509 certificate, while other objects are optional.

Lots of other stuff: TBD

Data Types

The table below shows the data types used by the SKS API. Note that multi-byte integers are stored in big-endian fashion.

Type	Length	Comment
byte	1	Unsigned byte (0 - 0xFF)
bool	1	Byte containing 0x01 (true) or 0x00 (false)
short	2	Unsigned two-byte integer (0 - 0xFFFF)
int	4	Unsigned four-byte integer (0 - 0xFFFFFFFF)
byte[]	2 + length	Array of bytes with a leading “short” holding the length of the data
blob	4 + length	Long array of bytes with a leading “int” holding the length of the data

If an array is followed by a number in brackets (“byte[32]”) it means that the array MUST be exactly of that length.

Return Values

All methods return a single-byte status code. In case the status is <> 0 there is an error and any expected succeeding values MUST NOT be read as they are not supposed to be available. Instead there is a second return value containing an UTF-8 encoded description in English to be used for logging and debugging purposes as shown below:

Name	Type	Comment
`Status`	byte	Non-zero (error) value
`ErrorString`	byte[]	A human-readable error description

Error Codes

The following table shows the standard SKS error-codes:

Name	Value	Comment
`ERROR_AUTHENTICATION`	1	This error is returned when there is something wrong with a supplied PIN-code. For more detailed information, see TBD
`ERROR_STORAGE`	2	There is no persistent storage available for the operation
`ERROR_MAC`	3	MAC does not match supplied data
`ERROR_CRYPTO`	4	Various cryptographic errors
`ERROR_NO_SESSION`	5	Session not found
`ERROR_SESSION_VERIFY`	6	The final step in the provisioning session failed to verify
`ERROR_NO_KEY`	7	Key not found
`ERROR_ALGORITHM`	8	Unknown or not fitting algorithm

Encrypted Data

During provisioning encrypted data is occasionally exchanged between the issuer and the SKS using a key based on the session variables established during the createProvisioningSession call. The encryption key is created by the following key derivation scheme:

```
EncryptionKey = HMAC-SHA256 (SK, ClientSessionID ||
                                 ServerSessionID ||
                                 IssuerURI ||
                                 "Encryption Key")
```

The **`EncryptionKey`** is used with the AES256-CBC algorithm.

MAC Operations

In order to verify the integrity of provisioned data, most of the provisioning methods requires that the data-carrying arguments are included in a MAC (Message Authentication Code) operation as well. Unless stated otherwise, MAC operations are based on the session variables established during the createProvisioningSession call and use the following scheme:

`MAC` = HMAC-SHA256 (*MethodName* || **`SK`** || **`ClientSessionID`** || **`ServerSessionID`** || **`IssuerURI`**, *Data*...)

The *MethodName* is simply the string literal of the target method like **`"closeProvisioningSession"`**, while *Data* represent the arguments in declaration order unless otherwise noted.

Argument data that is to be included in MAC operations MUST only include the content data, not length etc. See Data Types.

SKS Attestations

Except for the createProvisioningSession call, SKS attestations during provisioning sessions are using symmetric keys derived as for MAC Operations where *MethodName* is **`"SKS Attestation"`**.

Method List

This section provides a (*not very complete...*) list of the SKS methods. The number in parenthesis holds the decimal value used to identify the method in a call. Method calls are formatted as strings of bytes where the first byte is the method ID and the succeeding bytes the applicable argument data.

createProvisioningSession (1)

Input

Name	Type	Comment
`ServerSessionID`	byte[32]	Server nonce value
`ClientSessionID`	byte[32]	Client nonce value
`IssuerURI`	byte[]	UTF-8 encoded URI identifying the issuer. In KeyGen2 this is the URL to which the result of this method is POSTed. The string MUST NOT exceed 1024 bytes
`IssuerPublicKey`	byte[]	RSA server key (in X.509 DER format), for encrypting the session key (**`SK`**). The size of the key MUST match RSA capabilities
`Updatable`	bool	True if the session is supporting post provisioning updates
`ClientOperationLimit`	short	Constraint for thwarting cryptographic attacks on **`SK`** by limiting the number of externally visible SKS-generated signed and/or encrypted data objects
`SessionLifeTime`	int	Validity of the provisioning session in seconds

Output

Name	Type	Comment
`Status`	byte	See Return Values
`EncryptedSessionKey`	byte[]	Encrypted **`SK`**
`SessionKeyAttest`	byte[]	**`SK`** attestation signature
`ProvisioningHandle`	int	Local handle to created provisioning session

`createProvisioningSession` is the foundation for provisioning keys in an SKS. It performs the following steps in an *atomic* fashion:

- Generates a *random*, *secret* 32-byte **`SK`** (Session Key).
- Internally stores **`SK`**, **`ClientSessionID`**, **`ServerSessionID`**, **`IssuerURI`**, **`Updatable`**, **`ClientOperationLimit`**, current time + **`SessionLifeTime`** and returns a handle to the storage location in **`ProvisioningHandle`**.
- **`EncryptedSessionKey`** = ***Encrypt*** (**`IssuerPublicKey`**, **`SK`**)
- **`SessionKeyAttest`** = ***Sign*** (**`AttestationPrivateKey`**,
  HMAC-SHA256 (**`SK`**, **`ClientSessionID`** ||
  `ServerSessionID` ||
  `IssuerPublicKey` ||
  `IssuerURI` ||
  `Updatable` ||
  `ClientOperationLimit` ||
  `SessionLifeTime`))

The purpose of **`createProvisioningSession`** is creating a shared session key (**`SK`**) that is only known by the issuer and the SKS. In addition, the SKS is authenticated by the issuer.

`SK` is used for *authenticating* and *encrypting* data that is exchanged between the issuer and the SKS during subsequent steps in the provisioning session.

If any succeeding operation associated with the provisioning session (through **`ProvisioningHandle`**), is regarded as incorrect by the SKS, *the session is immediately terminated and removed from internal storage*.

An SKS SHOULD only constrain the number of simultaneous sessions due to lack of storage.

A provisioning session SHOULD NOT be terminated due to power down of the SKS.

Notes

Encrypt uses the RSAES-PKCS1-v1_5 algorithm.

Sign uses DIAS or RSASSA-PKCS1-v1_5 signatures for RSA keys and ECDSA for EC keys with SHA256 as the hash function.

The **`ProvisioningHandle`** is guaranteed to be unique and never reused.

closeProvisioningSession (2)

Input

Name	Type	Comment
`ProvisioningHandle`	int	Local handle to a provisioning session
`GeneratedKeys`	short	*Expected result*. What the issuer considers "has been ordered"
`DeletedKeys`	short	
`ClonedKeys`	short	
`ReplacedKeys`	short	
`ExtensionObjects`	short	
`MAC`	byte[32]	Vouches for the authenticity of the *expected result* parameters. See MAC Operations

Output

Name	Type	Comment
`Status`	byte	See Return Values
`AttestedResponse`	byte[32]	Attestation of the string **`"Success"`**. See SKS Attestations

`closeProvisioningSession` terminates a provisioning session and returns a proof of successful operation to the issuer. However, success status will only be returned if *all* of the following conditions are valid:

- There is an open provisioning session associated with **`ProvisioningHandle`**
- **`MAC`** matches the *expected result* parameters
- The *expected result* matches the SKS' internal calculations
- All generated keys are fully provisioned which means that matching public key certificates have been deployed. See setCertificatePath

When a provisioning session has been successfully closed by this method, it remains stored (until all keys associated with it have been deleted), but will only be a target for future updates if its **`Updatable`** flag is true.

abortProvisioningSession (3)

Input

Name	Type	Comment
`ProvisioningHandle`	int	Local handle to a provisioning session

Output

Name	Type	Comment
`Status`	byte	See Return Values

`abortProvisioningSession` is intended to be used by provisioning middleware if an unrecoverable error occurs in the communication with the issuer, or if a user cancels a session. If there is a matching and still *open* provisioning session, all associated data is removed from the SKS, otherwise an error is returned.

createPUKPolicy (5)

Input

Name	Type	Comment
`ProvisioningHandle`	int	Local handle to a provisioning session
`ID`	byte[]	PUK ID string with a maximum length of 32 bytes
`EncryptedValue`	byte[]	Encrypted PUK value. See Encrypted Data
`Format`	byte	Format of PUK strings. See PIN and PUK formats
`RetryLimit`	byte	Number of incorrect PUK values (*in a sequence*), forcing the PUK object to permanently lock up. A zero value indicates that there is no limit but that the SKS will introduce an *internal* 1-10 second delay *before* acting on an unlock operation in order to thwart exhaustive attacks

Output

Name	Type	Comment
`Status`	byte	See Return Values
`PUKPolicyHandle`	int	Non-zero local handle to created PUK policy object

`createPUKPolicy` creates a PUK policy object that is meant to be referenced by the createPINPolicy method. The purpose of a PUK is to facilitate a master key for unlocking keys that have locked-up due to faulty PIN entries. See TBD.

PIN and PUK formats

Name	Value	Comment
Numeric	0x00	0 - 9
Alphanumeric	0x01	0 - 9, A - Z
UTF-8	0x02	Any valid UTF-8 string
Binary	0x03	Binary value, typically issued as hexadecimal data

Note that format specifiers only deal with how PINs and PUKs are treated in GUIs; internally key protection data is always stored as strings of bytes.

createPINPolicy (6)

Input

Name	Type	Comment
`ProvisioningHandle`	int	Local handle to a provisioning session
`ID`	byte[]	PIN ID string with a maximum length of 32 bytes
`PUKPolicyHandle`	int	Handle to a governing PUK policy object or zero
`UserDefined`	bool	True if PINs belonging to keys governed by the PIN policy are supposed to be set by the user or by the issuer. See ???
`UserModifiable`	bool	True if PINs can be changed by the user after provisioning
`Format`	byte	Format of PIN strings. See PIN and PUK formats
`RetryLimit`	byte	Number of incorrect PIN values (*in a sequence*), forcing the key to lock up. A zero is not allowed as it would mean that the key would always be locked
`Grouping`	byte	
`PatternRestrictions`	byte	
`MinLength`	byte	
`MaxLength`	byte	
`CachingSupport`	bool	True if middleware may cache PINs for this key
`InputMethod`	byte	Constraints on PIN input. See ???

Output

Name	Type	Comment
`Status`	byte	See Return Values
`PINPolicyHandle`	int	Non-zero local handle to created PIN policy object

`createPINPolicy` creates a PIN policy object that is meant to be referenced by the createKeyPair method.

If **`PUKPolicyHandle`** is zero no PUK is associated with the PIN policy object.

A **`PUKPolicyHandle`** value of 0xFFFFFFFF presumes that the target SKS supports a “device PUK”, *otherwise an error is returned*. The characteristics of device PUKs are out of scope for the SKS specification.

createKeyPair (7)

Input

Name	Type	Comment
ProvisioningHandle	int	Local handle to a provisioning session
ID	byte[]	Key ID string with a maximum length of 32 bytes
PINPolicyHandle	int	Handle to a governing PIN policy object or zero
PINValue	byte[]	PIN value must depending on **PINPolicyHandle** either be of zero length, contain a plain-text PIN value defined by the user, or constitute of an encrypted PIN set by the issuer (see Encrypted Data)
PrivateKeyBackup	bool	True if the generated private key is to be put in **EncryptedPrivateKey** for backup by the issuer
Migratable	bool	True if SKS should permit the key to be exported (in clear text) by the user
Updatable	bool	True if the key is subject to post provisioning updates. Note that this also requires the provisioning session's **Updatable** flag to be true, otherwise an error is returned
DeleteProtected	bool	True if the key needs a PUK in order to be deleted by a user. Note that this option requires that the key is associated with a PUK, otherwise an error is returned. A conforming SKS may ignore this flag since it does not introduce any vulnerabilities
ImportPrivateKey	bool	TBD
KeyUsage	byte	TBD
FriendlyName	byte[]	TBD
AlgorithmData	byte	TDB

Output

Name	Type	Comment
Status	byte	See Return Values
PublicKey	byte[]	Generated public key in X.509 DER representation
AttestedPublicKey	byte[]	Attestation of the authenticity of the generated public key and associated data. See SKS Attestations
EncryptedPrivateKey	byte[]	*Optional*. This element will only be created if **PrivateKeyBackup** is true. See Encrypted Data
KeyHandle	int	Local handle to created key-pair object

createKeyPair creates an asymmetric key-pair inside of the SKS according to the issuer's specification.

If **PINPolicyHandle** is zero the key is not PIN-protected.

A **PINPolicyHandle** value of 0xFFFFFFFF presumes that the target SKS supports a "device PIN", *otherwise an error is returned*. The characteristics of device PINs are out of scope for the SKS specification.

To assure the issuer that the generated key-pair actually resides in the SKS, the public key, together with attributes and protection objects are signed (attested) by the SKS according to the following *Data* scheme:

```
addData ("PUK Policy=");
if (PINPolicyHandle == 0 || PINPolicyHandle == 0xFFFFFFFF ||
    PINPolicyHandle.PUKPolicyHandle == 0)
  {
    addData ("No PUK");
  }
else if (PINPolicyHandle.PUKPolicyHandle == 0xFFFFFFFF)  // Device PUK
  {
    addData ("Device PUK");
  }
else  // Standard PUK
  {
    addData ("Standard");
    addData (PINPolicyHandle.PUKPolicyHandle.ID);
    addData (PINPolicyHandle.PUKPolicyHandle.RetryLimit);
    addData (PINPolicyHandle.PUKPolicyHandle.clearTextPUKValue ());
    addData (PINPolicyHandle.PUKPolicyHandle.Format);
  }
addData ("PIN Policy=");
if (PINPolicyHandle == 0)  // The key is not PIN protected
  {
    addData ("No PIN");
  }
else if (PINPolicyHandle == 0xFFFFFFFF)  // The key is protected by a device PIN
  {
    addData ("Device PIN");
  }
else  // Standard PIN protection
  {
    addData ("Standard");
    addData (PINPolicyHandle.ID);
    addData (PINPolicyHandle.UserDefined);
    if (!PINPolicyHandle.UserDefined)
      {
        addData (clearTextPINValue ());
      }
    addData (PINPolicyHandle.UserModifiable);
    addData (PINPolicyHandle.Format);
    addData (PINPolicyHandle.RetryLimit);
    addData (PINPolicyHandle.Grouping);
    addData (PINPolicyHandle.PatternRestrictions);
    addData (PINPolicyHandle.MinLength);
    addData (PINPolicyHandle.MaxLength);
    addData (PINPolicyHandle.CachingSupport);
    addData (PINPolicyHandle.InputMethod);
  }
addData ("Key=");
addData (ID);
addData (PublicKey);
addData (PrivateKeyBackup);
addData (Migratable);
addData (Updatable);
addData (DeleteProtected);
addData (ImportPrivateKey);
addData (KeyUsage);
addData (FriendlyName);
```

setCertificatePath (8)

Input

Name	Type	Comment
`ProvisioningHandle`	int	Local handle to a provisioning session
`KeyHandle`	int	Local handle to a key-pair created in the provisioning session
`PathLength`	byte	Non-zero value holding the number of **`Certificate`** objects in the call
`Certificate...`	byte[]	X.509 DER-encoded certificate object which is *repeated* as defined by **`PathLength`**
`MAC`	byte[]	Vouches for integrity of the operation

Output

Name	Type	Comment
`Status`	byte	See Return Values

`setCertificatePath` attaches an X.509 certificate path to a previously created key-pair. See createKeyPair.

The SKS does not verify that the certificate path and the public key match for keys having the **`ImportPrivateKey`** flag set because that would disable the restorePrivateKey method. For other keys, the SKS MAY perform such a test although it is redundant since the **`MAC`** is assumed to cater for the binding between certificate path and the generated public key. That is, a conforming SKS MAY always treat certificate path data as an “array of blobs”.

Note that **`Certificate`** objects MUST form an *ordered* certificate path so that the first object denotes the end-entity certificate holding the public key of the target key-pair.

The certificate path MUST NOT contain any “holes” but does not have to be complete (include all CAs).

The **`MAC`** uses the method described in MAC Operations while *Data* is arranged as follows:

Data = **`KeyHandle.PublicKey`** || **`Certificate...`**

restorePrivateKey (20)

TBD

Sample Session

The following provisioning sample session shows the *sequence* for creating an X.509 certificate with a matching PIN-protected private key:

`ProvisioningHandle` = createProvisioningSession (…);

`PUKPolicyHandle` = createPUKPolicy (**`ProvisioningHandle`**, ...);

`PINPolicyHandle` = createPINPolicy (**`ProvisioningHandle`**, , **`PUKPolicyHandle`**, ...);

`KeyHandle` = createKeyPair (**`ProvisioningHandle`**, , **`PINPolicyHandle`**, ...);

setCertificatePath (**`ProvisioningHandle`**, **`KeyHandle`**, ...);

closeProvisioningSession (**`ProvisioningHandle`**, ...);

Note that **`Handle`** variables are only used by local middleware, while **`SK`**, **`MAC`**, **`ID`**, etc. are exclusively used between the issuer and the SKS.

If keys are to be created entirely locally, this requires a local software emulation of an issuer.

References

KeyGen2	TBD
DIAS	TBD
RSAES-PKCS1-v1_5	TBD
RSASSA-PKCS1-v1_5	TBD
ECDSA	TBD
AES256-CBC	TBD
HMAC-SHA256	TBD
X.509	TBD
SHA256	TBD
TPM 1.2	TBD

Acknowledgments

There is a bunch of organizations, mailing-lists, and individuals that have been instrumental for the creation of SKS. I need to check who would accept to be mentioned :-)

Author

Anders Rundgren
anders.rundgren@telia.com