Agenda

- PKCS#11 specifications
- OP-TEE and GPD TEE specifications
- Status in 3.12.0
- libckteec
- pkcs11 TA
- Next steps
PKCS#11 specifications

- Specifications
  - Considering the 2 latest version: v2.40-errata-01 & v3.0
  - 5 documents (base, profiles, 2 mechanisms docs, user guide) + Cryptoki C/C++ header files

- Interface to manage remote cryptographic operations & objects
  - Remote objects (raw data, formatted keys, certificates)
  - Remote operations using the remote objects (ciphering, authentication, key derivation, ...)

- User authentication
  - 1 SO + 1 user per token
  - PIN based authentication
  - Alternate authentication

```
CInitialize() C_OpenSession() C_Login() ...
C_CreateObject() C_GenerateKeyPair() C_DeriveKey() C_CopyObject() ...
C_FindObjects() C_GetAttributes() C_SetAttributes() ...
C_Encrypt() C_Decrypt() C_Sign() C_Verify() ...
```
PKCS#11 as a standard

Several standard packages support interfacing PKCS#11 tokens

OpenSSH  
- [fossies.org/linux/openssh/ssh-pkcs11-helper.8](fossies.org/linux/openssh/ssh-pkcs11-helper.8)

gnuTLS  

OpenSSL  
- No PKCS#11 engine in native OpenSSL. [OpenSC](https://www.opensc.org/) proposes one (RedHat, Ubuntu, ...)

python  
- [pypi.org/project/python-pkcs11/](pypi.org/project/python-pkcs11/)

AWS  
- Use PKCS#11 for the cryptographic operations control and alternate user authentication

LUKS  
- [0pointer.net/blog/unlocking-luks2-volumes-with-tpm2-fido2-pkcs11-security-hardware-on-systemd-248.html](0pointer.net/blog/unlocking-luks2-volumes-with-tpm2-fido2-pkcs11-security-hardware-on-systemd-248.html)

OP-TEE  
- :-)

Warning: specifications may have weaknesses if not flaws and should be carefully handled
OP-TEE & GPD TEE specifications

- OP-TEE is an enclave that:
  - Manages isolated trusted applications (PKCS#11 token is not the sole secure service)
  - Manages secure objects as keys for secure operations
  - Leverages platform capabilities (HW accel., ...)
  - Supports Arm7/v8 Cortex-A CPUs, RiscV in progress
  - Mostly 2 clause BSD license terms
  - [https://github.com/OP-TEE](https://github.com/OP-TEE)

  Started in 2014, 3.x.0 series since 2018, latest is 3.12.0

- OP-TEE is based on GPD TEE APIs
  - Does not expose object/crypto API functions to client
  - Client opens/closes sessions toward trusted app. and invokes commands (4 params)
  - In 2017 Linaro investigated on a pkcs11 TA, presented at HKG18-402
PKCS#11 Token in an OP-TEE TA

● Goal: deliver a PKCS#11 solution, reliable and maintained by the OP-TEE community

● Expose Cryptoki API to Linux user space application
  ○ ckteec library, 2 clause BSD license, hosted in optee_client.git
  ○ Converts Cryptoki API function call in a GPD TEE TA invocation command/arguments message

● PKCS#11 token is implemented in an OP-TEE TA
  ○ Based on GPD TEE APIs for secure storage & crypto
  ○ Implements PKCS#11 specification,
  ○ 2 clause BSD license, hosted in optee_os.git

● Regression tests: pkcs11 testsuite in OP-TEE xtest, hosted in optee_test.git
Achievements

- Slot and token discovery
- User session management
- User authentication (PIN & Linux ACL)
- Object (session and permanent) creation and generation (AES keys and generic secrets)
- Key derivation (by AES encryption)
- Ciphertext generation (a bit of AES: CBC & ECB)
- MAC computation (SHA*_HMAC)
- Digest (SHA*)
- Random number generation
- Self-made pkcs11 regression tests running in OP-TEE CI

Give a try!
Download OP-TEE manifest for Qemu Arm (**default.xml**(1)), build and run Qemu with
```
host> make run CFG_PKCS11_TA=y
```
From embedded shell: `sh> pkcs11-tool --list-token-slots`

(1): qemu_v8.xml: `make run CFG_PKCS11_TA=y CFG_USER_TA_TARGET_pkcs11=ta_arm64`
libckteec

- Cryptoki API in Linux userland
  - 1 Cryptoki API function for 1 pkcs11 TA command ID
  - Serialize client arguments to sent to TA (attributes lists, various structures passed)
  - Deserialize data sent back from TA (object attributes retrieved)
  - No complex processing expected: a thin API wrapper

- As of pre-3.13.0, almost all the main API functions are defined in pkcs11 TA API or will soon be.

  - C_Initialize()
  - C_Finalize()
  - C_GetInfo()
  - C_GetFunctionList()
  - C_GetSlotList()
  - C_GetSlotInfo()
  - C_GetTokenInfo()
  - C_CloseAllSessions()
  - C_GetSessionInfo()
  - CK_C_Login()
  - C_Login()
  - C_Logout()
  - C_CreateObject()
  - C_CopyObject()
  - C_InitToken()
  - C_InitPIN()
  - C_SetPIN()
  - C_OpenSession()
  - C_CloseSession()
  - C_DestroyObject()
  - C_GetObjectSize()
  - C_GetAttributeValue()
  - C_SetAttributeValue()
  - C_FindObjectsInit()
  - C_FindObjects()
  - C_FindObjectsFinal()
  - C_EncryptInit()
  - C_Encrypt()
  - C_EncryptUpdate()
  - C_EncryptFinal()
  - C_DecryptInit()
  - C_Decrypt()
  - C_DecryptUpdate()
  - C_DecryptFinal()
  - C_DigestInit()
  - C_Digest()
  - C_DigestUpdate()
  - C_DigestFinal()
  - C_SignInit()
  - C_SignUpdate()
  - C_SignFinal()
  - C_VerifyInit()
  - C_Verify()
  - C_VerifyUpdate()
  - C_VerifyFinal()
  - C_GenerateKey()
  - C_GenerateKeyPair()
  - C_WrapKey()
  - C_UnwrapKey()
  - C_DeriveKey()
  - C_SeedRandom()
  - C_GenerateRandom()

- Few are still missing, contributions are welcome:

  - C_GetOperationState()
  - C_SetOperationState()
  - C_SignRecoverInit()
  - C_SignRecover()
  - C_VerifyRecoverInit()
  - C_VerifyRecover()
  - C_DigestEncryptUpdate()
  - C_DecryptDigestUpdate()
  - C_SignEncryptUpdate()
  - C_DecryptVerifyUpdate()
  - C_GetFunctionStatus()
  - C_CancelFunction()
  - C_WaitForSlotEvent()
pkcs11 TA

- Client sessions
  - TA can implements several PKCS#11 tokens
  - Authentication based on a hash of client PIN/credentials
  - Session and object references are registered in lists in the TA space

- Objects
  - An object is a list of attributes built as a serialized byte stream
  - When object is created, attributes are added in a PKCS#11 consistent way
  - When object is used, TA checks object is visible/usable to the client for the operation

- Crypto operations
  - A token can executes a single operation at a time: the active processing.
    It must be initialized and finalized, as specified in PKCS#11.
  - Object used or generated during a operation is verified against PKCS#11 rules:
    Token state, object constraints, mechanism constraints, operation constraints, ...
  - TA relies on GPD TEE API for crypto and object storage
User authentication

- Standard default PIN based authentication (SO and user)

- Linux ACL based authentication: no PIN, only caller user and/or group IDs
  - Contributions from Vesa and Eero from Vaisala Oyj
  - Use of ACL TEE client identity: github.com/OP-TEE/optee_os/pull/4222 and related
  - Proposed configuration tool: github.com/OP-TEE/optee_client/pull/259

- Other alternate authentication can be considered
  - Coupled ACL + PIN
  - Dedicated platform means (i.e. HW under OP-TEE control)
  - ...

Testing

- A new pkcs11 testsuite is added in OP-TEE's xtest
  - For each new feature in pkcs11 TA, a xtest is implemented
  - Tests legitimate and invalid manipulations of objects/operations through Cryptoki API
  - Also tests the crypto algorithm minimal compliance (xtest test vectors and means)
  - Integrated in OP-TEE CI
    - Build with \texttt{CFG_PKCS11_TA=y}
    - From embedded shell: \texttt{sh> xtest -t pkcs11}

- \texttt{pkcs11test}
  - \texttt{pkcs11test} is PKCS#11 tester tool which uses Google Test.
    - Build: \texttt{sh> make CXX=/path/to/aarch64-linux-gnu-g++ AR=/path/to/aarch64-linux-gnu-ar}
    - From embedded shell: \texttt{sh> pkcs11test -m libckteec.so -s 0 --gtest_filter=<test name>}

Note: This testing is WIP. We are using these tests as we develop features for basic sanity. You may see failures when testing.
Testing

- **SoftHSM**
  - Is a software based implementation of HSM
  - Has a rich unitary test library which we are building standalone and using with libckteec.so
  - Steps to compile and use it can be found at [https://github.com/ruchi393/softhsm-ut-arm](https://github.com/ruchi393/softhsm-ut-arm)

- **pkcs11-tool**
  - Integrated in Buildroot environment
  - Get tokens/slots info
    
    ```
    pkcs11-tool --show-info    pkcs11-tool --list-token-slots    pkcs11-tool --list-mechanisms
    ```
  - Initialize token and user PIN
    
    ```
    pkcs11-tool --init-token --label test-token --so-pin 1234567890
    pkcs11-tool --label test-token --login --so-pin 1234567890 --init-pin --pin ABCDEFGHIJ
    ```
  - Generate AES Key
    
    ```
    pkcs11-tool --token-label foo --pin 123 --keygen --key-type AES:16 --id 1 --label my-key
    ```
  - List Objects
    
    ```
    pkcs11-tool --token-label test-token --list-objects
    ```
Next steps

- Wrap/unwrap keys
- RSA ciphering and authentication   <--- next steps before real world application
- ECDSA & ECDH   <---------------------- next steps before real world application
- DSA, DH
- More symmetric ciphers, MACs and KDFs
- Improve data storage
- Garbage collection of secure storage content   <--- needed for long term stability
- Documentation in optee docs.
- Enhance tokens isolation and parallelization
- Test results improvements - pkcs11test and SoftHSM
- ...

Contributions are welcome!
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Thank you

Accelerating deployment in the Arm Ecosystem