Secure Storage Updates in OP-TEE: What's new since SFO15 and what's left to do?

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Agenda

- What is secure storage?
- OP-TEE timeline
- What's new?
  - Framework for multiple storage backends
  - RPMB (Replay-Protected Memory Block)
  - SQLite
  - Encryption
  - `xtest` updates
- Next steps

What is Secure Storage?

- Persistent data store for crypto keys or other application-specific data
- Accessible to Trusted Applications only
  - Each TA has its own storage (TA isolation)
- Isolated from the non-secure world
  - Secure Storage data be read, modified or deleted by user applications or the OS kernel
- OP-TEE implements the GlobalPlatform™ *TEE Internal Core API v1.1*
  - Chapter 5: *Trusted Storage API for Data and Keys ; Persistent Object [Enumeration] Functions* and *Data Stream Access Functions*

```
TEE_OpenPersistentObject()
TEE_CreatePersistentObject()
TEE_CloseAndDeletePersistentObject1()
TEE_RenamePersistentObject()
TEE_ReadObjectData()
TEE_WriteObjectData()
TEE_TruncateObjectData()
TEE_SeekObjectData()
```

```
TEE_AllocatePersistentObjectEnumerator()
TEE_FreePersistentObjectEnumerator()
TEE_ResetPersistentObjectEnumerator()
TEE_StartPersistentObjectEnumerator()
TEE_GetNextPersistentObject()
```

OP-TEE Timeline

LCU14 HKG15 SFO15 BKK16 LAS16

0.1.0 0.2.0 0.3.0 1.0.0 1.1.0 2.0.0 2.1.0 (next)

`struct tee_file_operations`
Encryption
Atomicity

RPMB

xtest 20000 (corruption tests)

Multiple storage support

Better TA isolation
SQLite storage

Multiple storage support

- OP-TEE < 2.0.0
  - Secure storage is implemented on top of the Rich OS filesystem. We call it the “REE FS”
  - Trusted Application may only use TEE_STORAGE_PRIVATE as the storageID parameter
- OP-TEE = 2.0.0
  - Replay Protected Memory Block (RPMB) storage is introduced. It is a compile-time option to replace the REE FS (`CFG_RPMB_FS=y`).
- OP-TEE = 2.1.0
  - Code is refactored to allow for compile time and runtime selection of the storage backend
  - Compile time options (both may be enabled simultaneously):

    ```
    CFG_REE_FS ?= y ; CFG_RPMB_FS ?= n
    ```

  - Runtime flags used by Trusted Applications:

    ```
    #define TEE_STORAGE_PRIVATE         0x00000001
    #define TEE_STORAGE_PRIVATE_REE     0x80000000
    #define TEE_STORAGE_PRIVATE_RPMB    0x80000100
    ```

- OP-TEE > 2.1.0 (next)
  - SQLite storage is introduced: `CFG_SQL_FS ?= n`

    ```
    #define TEE_STORAGE_PRIVATE_SQL     0x80000200
    ```

Replay Protected Memory Block support (1)

- Added in 2.0.0
- OP-TEE had some legacy RPMB code which was re-worked recently
- Main source files:

```
core/tee/tee_svc_storage.c
core/tee/tee_rpmb_fs.c
core/tee/tee_fs_key_manager.c
```

- FS layout is as follows:

```
[ Partition data (512 bytes) | FAT entries -> ... <- File blocks ]
```

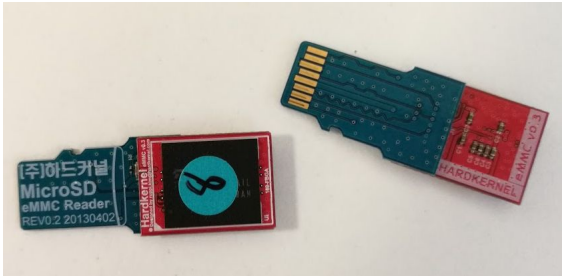
- File Allocation Table entries are dynamically allocated from the bottom while file blocks are allocated from the top
- The allocator is `tee_mm_alloc()` / `tee_mm_alloc2()`

Replay Protected Memory Block support (2)

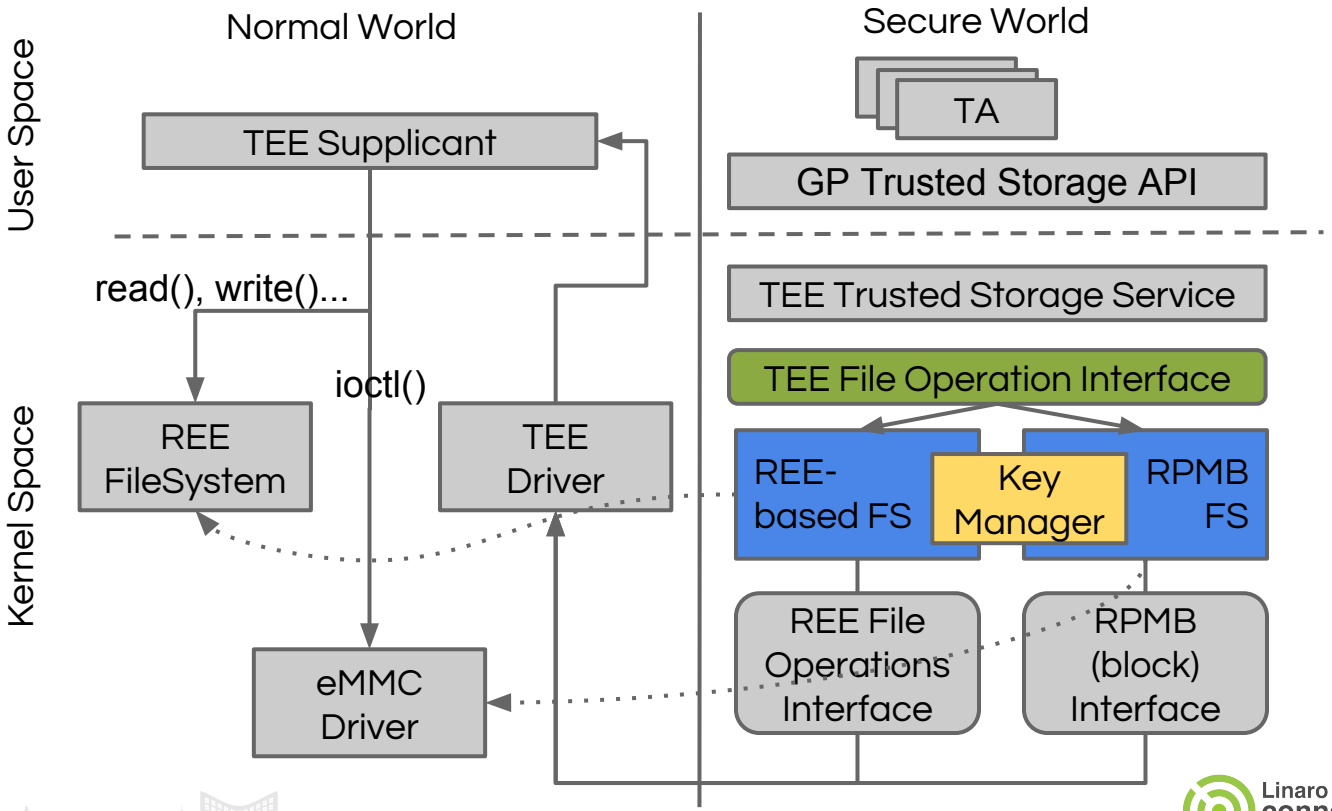
- eMMC device ID is selected at compile time
  - `CFG_RPMB_FS_DEV_ID ?= 0` in `mk/config.mk`
  - Will use `/dev/mmcblk0rpmb`
- Device is accessed through Normal World (`tee-supplicant`)
  - There is no MMC driver inside OP-TEE
- `tee-supplicant` contains emulation code so it's easy to test without a real device
  - `RPMB_EMU := 1` in `tee-supplicant/Makefile`
  - Comment out to access the real device
- RPMB key is programmed on first use
  - SHA256(HUK) or a predefined test key if `CFG_RPMB_TESTKEY = y`
  - /!\ possible attack: replace the eMMC with a new one (or simulate the same) and the key will leak out. We'll fix that.

Replay Protected Memory Block support (3)

- Atomicity: read/write/rename etc. can't leave objects in a partially modified state
  - FAT block is updated only after data blocks have been written successfully
  - RPMB spec ensures atomic write of rel_wr_blkcnt blocks or less (at least 1), this is enough for our need
  - Data writes larger than rel_wr_blkcnt cannot be updated in-place ; allocate/read/update/write/commit to FAT instead
- **HiKey** can access the onboard eMMC since kernel 4.8-rc1
  - Commit af63762 ("mmc: dw_mmc: k3: add MMC_CAP_CMD23")
  - An external eMMC module with a microSD adapter can also be used



Replay Protected Memory Block support (4)



SQLite (1)

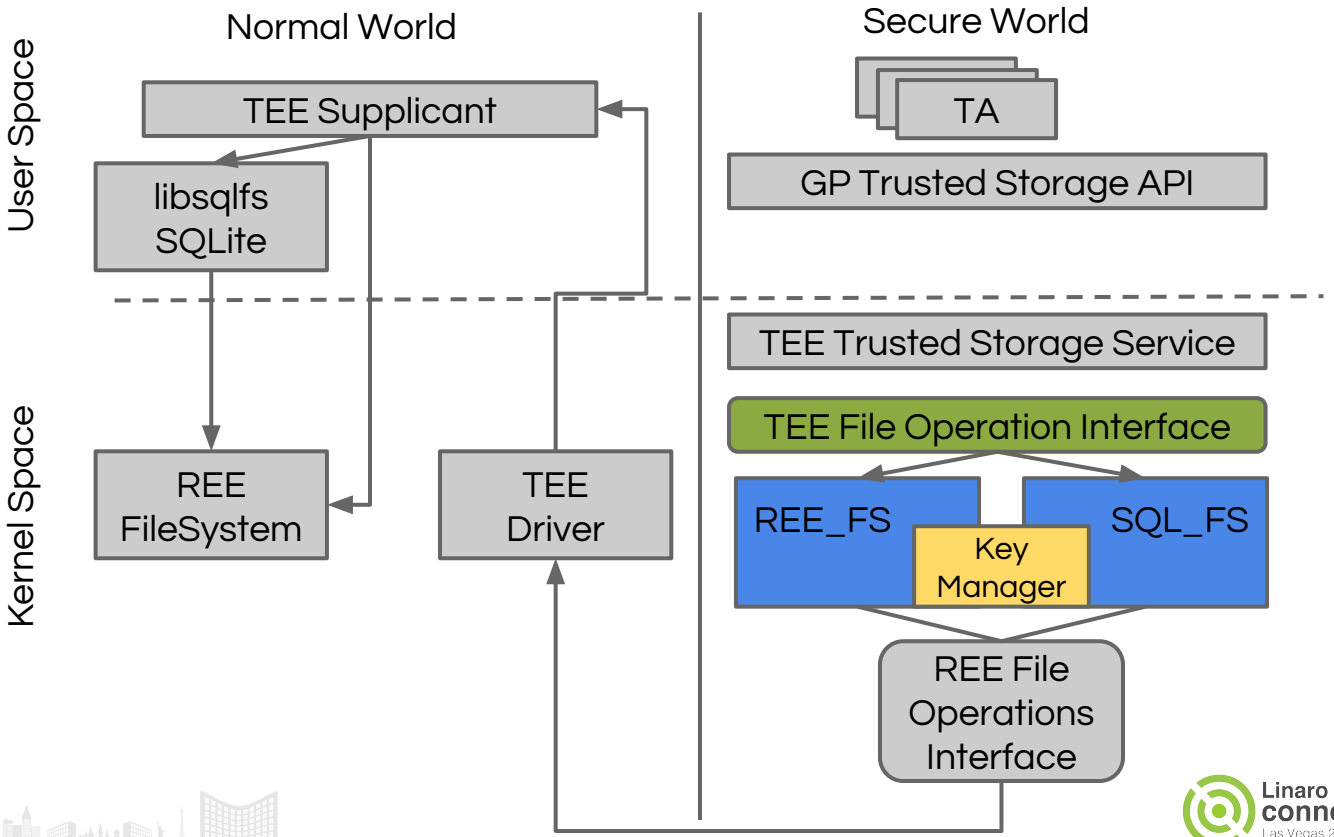
- A SQLite backend is proposed as a simpler and more robust alternative to the REE FS
- Based on SQLite3 (public domain) and libsqlfs (LGPLv2 or later)
- Moves the complexity of handling atomic updates from secure world to normal world (`tee-supplicant`). Indeed, libsqlfs provides:

```
sqlfs_begin_transaction(fs);
sqlfs_complete_transaction(fs, rollback);
```

- TA data are stored in a single file in the Normal World filesystem:

```
/data/tee/sstore.db
```

SQLite (2)


Normal World
Secure World
User Space
Kernel Space
TEE Supplicant
libsqlfs
SQLite
TA
GP Trusted Storage API
TEE Trusted Storage Service
TEE File Operation Interface
REE
FileSystem
TEE
Driver
REE_FS
Key
Manager
SQL_FS
REE File
Operations
Interface

Encryption (1)

- Data Encryption is turned on with CFG_ENC_FS=y (default y).
  - Useful even for RPMB, since the device is accessed through the Normal World
- Authenticated block encryption, 1 key per file (File Encryption Key).
- FEK is AES-encrypted using a 256-bit Trusted app Storage Key (TSK) then stored in the file's metadata
- The TSK is derived from the SSK and the TA UUID using HMAC_SHA256
  - Prevents TA2 from accessing data owned by TA1 when REE FS files are moved from storage area of TA1 to TA2
- The SSK is derived from a Hardware Unique Key (HUK) and a constant string using HMAC_SHA256

Encryption (2)

- REE FS, SQL FS:
  - Metadata are always authenticated and encrypted
  - Data may or may not be authenticated and encrypted depending on CFG_ENC_FS (default: y)
  - Algorithm is AES-GCM
- RPMB FS:
  - Metadata are never encrypted
  - Data may or may not be encrypted depending on CFG_ENC_FS.
  - Data and metadata are always authenticated (RPMB protocol)
  - Data encryption algorithm is AES-CBC with ESSIV (no need for GCM as above because authentication is handled by RPMB)

`xtest` updates

- Test all supported backends
  - Client application automatically includes `conf.h` generated during OP-TEE build, so all CFG_* settings may be used
  - `xtest 6xxx` loops on all supported storage IDs
- Test TA storage isolation
  - xtest 6015
  - Checks that two TAs won't share data
  - Checks that REE FS can't be fooled into opening data storage belonging to another TA
- Concurrency test
  - xtest 6016
  - 4 threads (pthread) run a loop, invoking the storage TA to perform create/write/verify/delete on distinct objects. TA has TA_FLAG_MULTI_SESSION.

What's next?

- RPMB: don't program key unless some debug/testing CFG_ is set
- Improve derivation of SSK from HUK
  - Should be done by the hardware crypto module. HUK should never be read by software.
  - Unfortunately, we have no such driver upstream :(
- Anti-rollback protection and controlled rollback for storage owned by non-secure OS: how?
- Prevent TA impersonation
  - Per-TA signing keys and use root key to sign key pairs only (not the TA itself)
  - Not only restricted to storage
- Further code simplifications?
- Is SQL FS useful? Should it replace REE FS? When?

Thank You

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