Rockchip TEE SDK Developer Guide

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Preface

Overview

This document mainly introduces Rockchip TEE firmware description, TEE environment construction, CA/TA development test, TA debugging method, TA signature method and precautions.

Intended Audience

This document is mainly applicable to the following engineers:

Technical Support Engineer

Software Development Engineer

Revision History

Version	Author	Date	Change Description
V1.00	ZZJ	2018-4-26	Initial Version
V1.10	ZZJ	2019-3-18	Add description of TEE in U-Boot；Distinguishing between V1 and V2 versions
V1.20	hisping	2019-6-4	Add description of secure storage
V1.30	hisping	2019-7-4	Modify description of secure storage
V1.40	hisping	2019-7-11	Add description of parameter.txt；Add description of kernel node which relate to TEE
V1.50	hisping	2019-8-8	Add description of error when compile rk_tee_user
V1.60	hisping	2021-1-27	Add description of changes to optee v1 kernel driver
V1.61	hisping	2021-3-4	Add description of unsupported error for rkfs
V1.70	hisping	2021-5-13	Add description of SECSTOR TA
V1.71	WXB	2021-5-14	Upgrade the CA/TA test program developed by RK, Update the description of the document
V1.72	hisping	2021-6-4	Modify description of TEE Macro in U-Boot
V1.73	hisping	2021-6-4	Add description of ENCRYPT TA
V1.74	WXB	2021-6-17	Add description of anti rollback for REE FS TA
V1.75	hisping	2021-7-5	Add description of TA debug method
V1.76	hisping	2021-7-8	Add description of TA view function call stack method
V1.77	hisping	2021-9-3	Revise TA signature chapter
V1.78	hisping	2021-9-6	Add description of secure storage performance test
V1.79	ZZJ	2021-9-10	Optimize partial format
V1.80	WXB	2021-9-10	Add description of TA API

Version	Author	Date	Change Description
V1.81	hisping	2021-10-12	Modify description of secure storage performance test
V1.82	WXB	2021-10-15	Add more API in TA API section
V1.83	ZZJ	2021-10-18	Optimize partial format
V1.84	WXB	2021-11-22	Add description of strong and weak security level , Update CA/TA description
V1.85	WXB	2021-11-26	Add OTP description chapter, Update OTP API, Adjust CA/TA description
V1.86	WXB	2021-11-30	Add reading guide chapter
V1.87	hisping	2022-06-22	Add rk_tee_service chapter
V1.9.0	hisping	2023-05-29	Supplement the details of each chapter, Add Step By Step chapter, Update Memory description, Update Secure Storage, Update OTP description.
V1.10.0	ZZJ	2023-06-02	Optimize partial format
V1.11.0	hisping	2024-01-23	Add description of U-Boot Run User TA, Add description of print secure memory, Add description of Test xtest Add description of HW Crypto API, Add description of Derive Key API
V1.12.0	hisping	2024-07-30	Supplement the details of Encrypt TA, Add description of soft ta encryption key.
V1.13.0	hisping	2024-11-15	Supplement the details of each chapter, add the Step By Step chapter with TA signature.
V1.14.0	hisping	2024-12-06	Additional explanation on how to compile firmware for 32-bit platforms that supports running User TA.

Contents

1. Reading Guide

The following steps describes the document structure and how to use TEE on Rockchip SoCs. It can be used as a guide for developers.

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    - Confirm OP-TEE version, See OP-TEE Version Description section.
    - Strong and weak security level configuration, See Solution of optional strong or weak security levels section.
    - TA signature key, See TA Signature section.
    - Additional protection mechanism of TA, See Built-in TA into secure storage, Encrypt TA, REE FS TA anti-rollback sections.
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2. Introduction to TrustZone

2.1 What is TrustZone

ARM TrustZone technology is a system wide security method for a large number of applications on high-performance computing platforms, including secure payment, digital rights management (DRM), enterprise services and web-based services.

TrustZone Technology and Cortex ™- A Processor is tightly integrated and expanded in the system through AMBA-AXI bus and specific TrustZone system IP block. This system approach means that peripherals such as secure memory, encryption blocks, keyboards, and screens can be protected from software attacks.

The devices developed according to the recommendations of the TrustZone Ready Program and utilizing the TrustZone technology provide a platform that can support a fully trusted execution environment (TEE) as well as security aware applications and security services.

The latest devices such as smart phones and tablets provide consumers with a high-value experience based on an extended service set. Mobile devices have developed into an open software platform that can download various large-scale applications from the Internet. These applications are usually verified by the device OEM to ensure quality, but not all functions can be tested, and attackers are constantly creating more and more malicious code targeting such devices.

At the same time, the demand for mobile devices to handle important services is increasing. From being able to pay, download and watch the latest Hollywood blockbusters in a specific period of time to being able to pay bills and manage bank accounts remotely through mobile phones, all these indicate that new business models have begun to emerge.

These development trends have made mobile phones likely to become the next software attack target of malware, Trojan horses, rootkits and other viruses. However, by applying advanced security technology based on ARM TrustZone technology and integrating SecurCore ™ Anti tamper elements can be used to develop devices that can provide an open operating environment with rich functions and powerful security solutions.

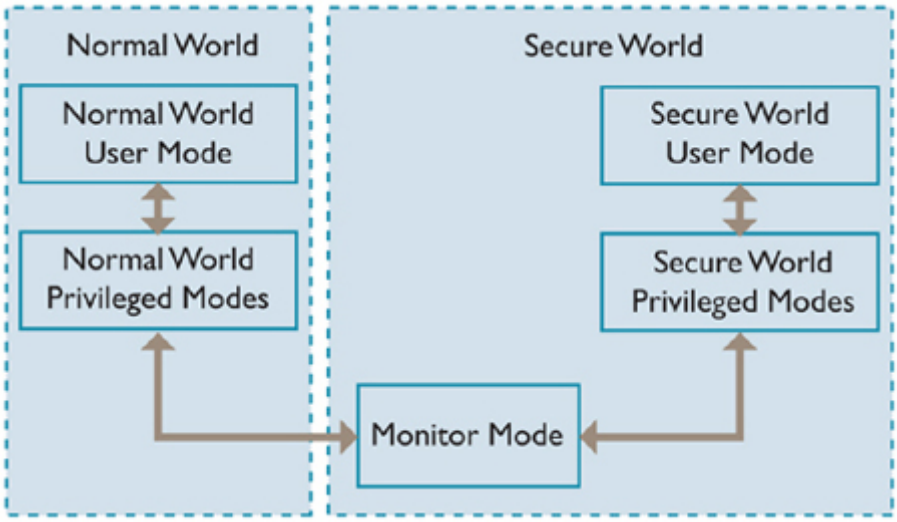
The trusted application adopts the SoC (running trusted execution environment) based on TrustZone technology, which is separated from the main OS to prevent software/malware attacks. TrustZone can be switched to safe mode to provide isolation supported by hardware. Trusted applications are usually containable, such as allowing trusted applications from different payment companies to coexist on one device. The processor supports ARM TrustZone technology, which is the basic function of all Cortex - A processors, and is introduced through the security extension of ARM architecture. These extensions provide a consistent programmer model across vendors, platforms, and applications, while providing a real hardware supported security environment.

2.2 Architecture

2.2.1 Hardware architecture

The TrustZone hardware architecture is designed to provide a security framework that enables devices to withstand the many specific threats they will encounter. TrustZone technology provides an infrastructure that allows SoC designers to choose from a large number of components that can implement specific functions in a secure environment, without providing a fixed and unchanging security solution.

The main security goal of the architecture is to support the construction of a programmable environment to prevent specific attacks on the confidentiality and integrity of assets. Platforms with these features can be used to build a wide range of security solutions, which are time-consuming and laborious to build using traditional methods.



System security can be ensured by isolating all SoC hardware and software resources so that they are located in two areas (a secure area for security subsystems and a normal area for storing all other content). AMBA3 AXI supporting TrustZone ™ , The hardware logic in the bus construction can ensure that normal area components cannot access security area resources, thus building a strong boundary between the two areas. The design of placing sensitive resources in a secure area, as well as running software reliably in a secure processor core, ensures that assets can withstand numerous potential attacks, including those that are often difficult to protect (for example, entering passwords using a keyboard or touch screen). By isolating security sensitive peripherals in the hardware, designers can limit the number of subsystems that need to pass the security assessment, thus saving costs when submitting security certification equipment.

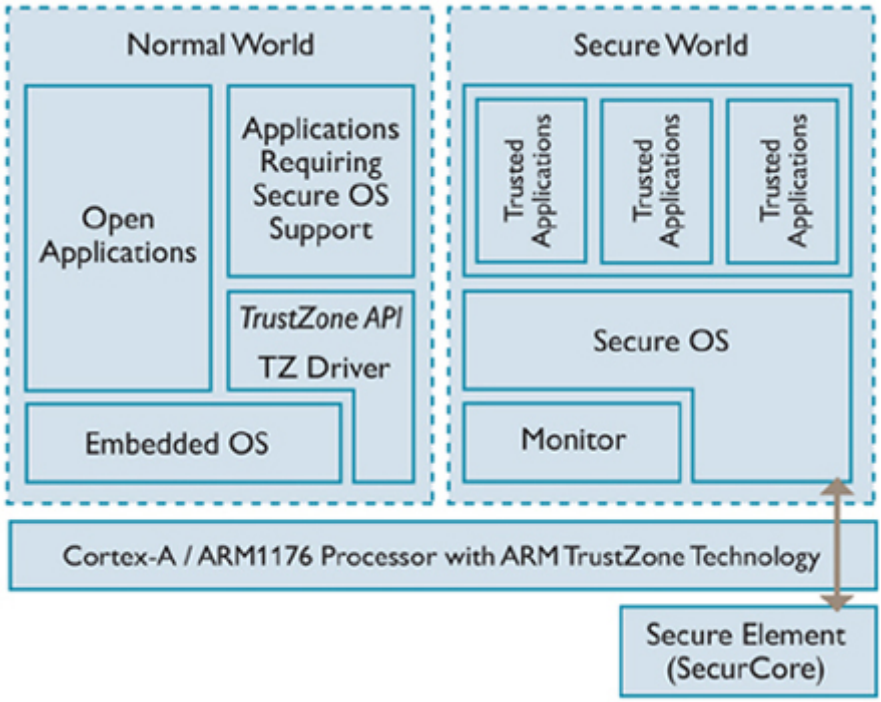
The second aspect of the TrustZone hardware architecture is the extension implemented in some ARM processor cores. With these additional extensions, a single physical processor core can safely and effectively execute code from both the normal area and the security area in a time slice manner. In this way, a dedicated security processor core is not required, which saves chip area and energy, and allows high-performance security software to run together with the general regional operating environment.

After changing the currently running virtual processor, the two virtual processors perform context switching through the new processor mode (called monitor mode).

The mechanisms used by the physical processor to enter the monitor mode from the normal area are closely controlled, and these mechanisms are always regarded as exceptions of the monitor mode software. The items to be monitored can be triggered by the software executing special instructions (security monitor call (SMC) instructions), or by a subset of the hardware exception mechanism. IRQ, FIQ, external data abort, and external prefetch abort exceptions can be configured to switch the processor to monitor mode.

The software executed in the monitor mode is implementation defined, but it usually saves the state of the current area and restores the state of the area location to which it will switch. It then performs the operation returned from the exception to restart the processing in the restored area. The last aspect of the TrustZone hardware architecture is the security aware debugging infrastructure, which can control the access to security zone debugging without weakening the debugging visualization of common zones.

2.2.2 Software architecture



Implementing security zones in SoC hardware requires that certain security software be run in them and that sensitive assets stored in them be utilized.

There may be many software architectures that can be implemented by the security zone software stack on the processor core that supports TrustZone. The most advanced software architecture is the dedicated security zone operating system; The simplest is the synchronized code base placed in the security zone. There are many intermediate options between these two extreme architectures.

A dedicated security kernel can be a complex but powerful design. It can simulate the concurrent execution of multiple independent security zone applications, the runtime download of new security applications, and security zone tasks that are completely independent of the general zone environment.

These designs are very similar to the software stack you will see in the SoC, which uses two separate physical processors in an asymmetric multiprocessing (AMP) configuration. The software running on each virtual processor is an independent operating system, and each region uses hardware interrupts to preempt the currently running region and obtain processor time.

A tightly integrated design using communication protocols that associate secure area tasks with normal area threats that request them can provide many advantages of symmetric multiprocessing (SMP) designs. For example, in these designs, a security zone application can inherit the priority of common zone tasks it supports. This will result in some form of soft real-time response to the media application.

Security extension is an open component of ARM architecture, so any developer can create a customized security zone software environment to meet its requirements.

2.2.3 TrustZone and TEE

Applications such as payment, online banking, content protection, and enterprise authentication can improve their integrity, functionality, and user experience by leveraging three key elements provided by TrustZone technology enhanced devices:

1. Software secure execution environment to prevent malware attacks from rich operating systems
2. The hardware trust root can check the integrity of data and applications in the rich operation field to ensure that the security environment is not damaged
3. Access security peripherals on demand, such as memory, keyboard/touch screen, and even monitor

The device based on ARM TrustZone technology is combined with open APIs to provide a trusted execution environment (TEE). Developers need a new type of software to achieve its functions and consistency: this software is a trusted application. A typical trusted application can contain part of the code in both the normal area and the security area, for example, handling critical storage and manipulation. TEE also provides isolation from other trusted applications, enabling multiple trusted services to coexist.

The standardization of TEE API (managed by GlobalPlatform) will enable service providers, operators and OEMs to market interoperable trusted applications and services.

ARM TrustZone technology does not require separate security hardware to verify the integrity of devices or users. It does this by providing a true hardware trust root in the main handset chipset.

In order to ensure the integrity of the application, TrustZone also provides a secure execution environment (i.e., trust execution environment (TEE)), in which only trusted applications can run, so as to prevent attacks in the form of hackers/viruses/malware.

The TrustZone hardware provides isolation between TEE and software attack media. Hardware isolation can be extended to protect data input and output from physical peripherals (including keyboard/touch screen, etc.).

With these key functions, the chipset using TrustZone technology provides many opportunities to redefine the services that users can access (more and better services), how to access services (faster and easier), and where to access services (anytime, anywhere).

On most Android devices, the Android Boot loader does not verify the authenticity of the device kernel. Users who want to further control their devices may install the cracked Android kernel to root their devices. The cracked kernel allows super users to access all data files, applications and resources. Once the kernel is broken, the service will be rejected. If the kernel contains malware, the security of enterprise data will be compromised.

Secure Boot can effectively prevent the above problems. Secure Boot is a security mechanism that can prevent unauthorized boot loaders and kernels from being loaded during startup. Firmware images (such as operating systems and system components) that are encrypted and signed by a trusted, known authority are considered authorized firmware. The security boot component can form the first line of defense to prevent malicious software from attacking the device.

3. TEE Environment

3.1 OP-TEE Version Description

Android 7.1 and higher SDKs in Rockchip platform support TEE environment by default, TEE environment is not supported by default in versions earlier than Android 7.1

Linux SDK does not enable TEE environment by default, But you can refer to the following chapters to manually configure the TEE environment.

The TEE solution on Rockchip platform is OP-TEE, and the TEE API conforms to the GlobalPlatform standard.

At present, there are two versions of OP-TEE running on the rockchip platform, OP-TEE V1 and OP-TEE V2.

1. OP-TEE V1: RK312x, RK322x, RK3288, RK3328, RK322xh, RK3368, RK3399, RK3399Pro

2. OP-TEE V2: RK3326/PX30, RK3358, RK3308, RK1808, RV1109/RV1126, RK3566/RK3568, RK3588, RK3528, RK3562, RV1106 and subsequent new platforms

TEE library files, TA files, and TEE firmware is different between the two versions, Select TEE components according to the specific platform.

Platforms that are not listed in the OP-TEE V1 list can be considered platforms that adopt OP-TEE V2.

3.2 Parameter.txt

OP-TEE supports multiple secure storage file systems, as detailed in the "Secure Storage" section. Security partition is one of them. To use security partition, it is necessary to confirm that the partition is defined in the parameter.txt file which records the location and size information of each image. Security partition can be set by adding 0x00002000@0x000xxxxx(security) in parameter.txt, 0x00002000 indicates the size of 4M, 0x000xxxxx indicates the starting address, modify according to the actual parameter.txt

3.3 TEE firmware

TEE firmware can also be called TEE binary, Secure OS firmware, and on 64 bit platforms, it can also be called BL32.

The source code of TEE Secure OS is not open source by default, TEE binary file locat in directory `u-boot/tools/rk_tools/bin` or `rkbin/bin`.

1. The TEE binary of ARMv7 platform is packaged into trust.img by the tool `u-boot/tools/loaderimage`, The name of TEE binary is as follows:

   ```
   <platform>_tee_[ta]_<version>.bin
   such as: rkbin/bin/rk35/rk3506_tee_v1.26.bin
   such as: rkbin/bin/rk35/rk3506_tee_ta_v1.00.bin
   ```

   The name with [ta] support running user TA application, the name without [ta] do not support running user TA application.

   During U-Boot compilation,TOS.ini is used by default for firmware package, If config has defined CONFIG_TRUST_INI, Packaging firmware using the ini files.

   Taking RK3506 as an example, RK3506TOS.Ini is used by default for firmware packaging during compilation. RK3506TOS.Ini points to firmware without ta, so RK3506 does not support running User TA by default. If developers need to run User TA, they need to define CONFIG_TRUST_INI="RK3506TOS_TA.ini" in the config, which points to firmware with ta.

   The RK3506 quick start solution defaults to running TEE but not U-Boot, U-Boot cannot automatically reserve secure memory for TEE, So when using firmware with ta, it is necessary to add the following configuration under the reserved_memory node in the Kernel dts file, in order to reserve secure memory for TEE.

   ```
   trust@1 {
     reg = <0x3c00000 0x140000>;
   };
   ```

   For other platforms, U-Boot automatically reserves secure memory for TEE, without the need for additional configuration of Kernel dts.

2. The TEE binary of ARMv8 platform is packaged into trust.img by the tool `u-boot/tools/trust_merger`, The name of TEE binary is as follows:

   ```
   <platform>_bl32_<version>.bin
   such as: rkbin/bin/rk35/rk3588_bl32_v1.18.bin
   ```

3. If [BL32_OPTION] SEC=0 in rkbin/RKTRUST/.ini, It needs to be changed to SEC=1, Otherwise trust.img will not contain Secure OS and cannot run TEE services.

4. RK3566/RK3568, RK3588, RK3528, RK3562, RV1106, and subsequent new platforms will package the TEE binary into uboot.img without generating trust.img firmware.

The following print indicates that the OPTEE V1 platform TEE firmware has been run.

```
INF [0x0] TEE-CORE:init_primary_helper:337: Initializing (1.1.0-278-gef70f120a #9 Fri Sep 17 09:39:24 UTC 2021 aarch64)
INF [0x0] TEE-CORE:init_primary_helper:338: Release version: 1.2
INF [0x0] TEE-CORE:init_teecore:83: teecore inits done
INFO:   BL31: Preparing for EL3 exit to normal world
INFO:   Entry point address = 0x200000
INFO:   SPSR = 0x3c9
```

The following print indicates that the OPTEE V2 platform TEE firmware has been run.

```
I/TC: OP-TEE version: 3.13.0-897-g5813e173a
I/TC: OP-TEE memory: TEEOS 0x200000 TA 0xc00000 SHM 0x200000
I/TC: Primary CPU initializing
I/TC: Primary CPU switching to normal world boot
INFO:   BL31: Preparing for EL3 exit to normal world
INFO:   Entry point address = 0x200000
INFO:   SPSR = 0x3c9
```

3.4 TEE driver in U-Boot

At present, some safe operations need to be performed at the U-Boot level, For example, OP-TEE must be used to read some secure data.The OP-TEE Client code is implemented in U-Boot, U-Boot can communicate with OP-TEE through this interface. OP-TEE Client driver is under lib/optee_client, API conforms to GP specification.

3.4.1 Macro Definition

`CONFIG_OPTEE_CLIENT`, OP-TEE function main config.

`CONFIG_OPTEE_V1`, set by OP-TEE V1 platform.

`CONFIG_OPTEE_V2`, set by OP-TEE V2 platform.

`CONFIG_OPTEE_ALWAYS_USE_SECURITY_PARTITION`, The secure storage area will be selected according to the hardware if this macro is not enabled, use rpmb if device use EMMC, use security partition if device use NAND. After the macro is enabled, data is fixed store in the security partition, Not store in rpmb . The scope of this macro is the U-Boot stage, It do not affect the kernel and UserSpace.

RPMB has higher security and stability than security partition, but less convenience than security partition. If the device is replaced with another device's EMMC to this device, or if the CPU is replaced, all you need to do is use the burning tool to erase the flash and reburn the firmware when using security partitions, the burning tool cannot clear rpmb data and special firmware is needed to clear rpmb data when using rpmb. Please weigh the convenience and security of whether to enable this macro. Some platforms will default to enabling this macro, If you have high security requirements, you can remove this macro yourself.

3.4.2 Shared Memory

When U-Boot communicates with OP-TEE, the data must be stored in shared memory, You can use the `TEEC_AllocateSharedMemory()` to request shared memory, the shared memory size of each platform is different, and it is recommended that it should not exceed 1M, If it exceeds, it is recommended to split the data and transfer it for many times, Release shared memory by call `TEEC_ReleaseSharedMemory()`.

3.4.3 Secure Storage Test

3.4.3.1 Test method

Follow the steps below to perform the secure storage test. This test case will test the read/write function of secure storage, The test case will automatically check the hardware, the rpmb and security partition will be tested when the hardware uses emmc, Only security partition will be tested when the hardware uses nand. It is necessary to confirm that the U-Boot has turned on CONFIG_SUPPORT_EMMC_RPMB when the hardware uses emmc.

1. Enter the U-Boot command line: Device serial port connecting to PC, press ctrl+c in PC, Start device, It will stop at uboot.
2. Run: The following command starts the test.

```
=> mmc testsecurestorage
```

3.4.3.2 Troubleshooting

```
"TEEC: Could not find device"
```

The emmc or nand device is not found. Please check the driver in the U-Boot or the hardware.

```
"TEEC: Could not find security partition"
```

When the security partition is used for secure storage, the encrypted data will be stored in this partition. Please check whether the security partition is defined in parameter.txt

```
"TEEC: verify [%d] fail, cleanning ...."
```

When the security partition is used for secure storage for the first time, or the security partition data is illegally tampered, the security partition will be completely cleared.

```
"TEEC: Not enough space available in secure storage !"
```

There is not enough storage.

```
INF [0x0] TEE-CORE:storage_read_obj:201: Warning! head data not find!
ERR [0x0] TEE-CORE:storage_read_obj:210: cpu or emmc was replaced!
```

During U-Boot startup, key data will be stored by calling TEE, Key data is encrypted by TEE and stored in security partition or rpmb, And the encryption key is bound to the CPU；If the CPU is replaced, key data cannot be decrypted normally, resulting in U-Boot startup failure；If the emmc is replaced and used before, Old data exists in the security partition or rpmb, This error will also occur which causing U-Boot start fail；The solution is to clear the old data in the security partition or rpmb, format emmc directly if the security partition is used, If you use rpmb, you need to contact technical support to provide special firmware to clear the old data in rpmb.

```
“optee check api revision fail”
```

The U-Boot version does not match the TEE version, the U-Boot version is higher than the TEE version, The solution is as follows（choose one）:

1. Fallback U-Boot version to `cf13b78438 (tag: android-10.0-mid-rkr9) rockchip: spl: add rollback index check with otp`.
2. Revert the following commit:

   `396e3049bd rochchip: board: only map op-tee share memory as dcache enabled`

   `7a349fdcbd lib: optee_client: add optee initialize flag`

   `74eb602743 lib: optee_client: update to new optee msg for optee v1 platform`

   `102dfafc4a rochchip: board: map op-tee memory as dcache enabled`

Normally, the versions of Uboot and OP-TEE in released SDK are matched.

```
"optee api revision mismatch with u-boot/kernel, panic"
```

If it is printed in the U-Boot startup, It mean the U-Boot version does not match the TEE version, U-Boot version is lower than TEE version, Upgradeable U-Boot version to `396e3049bd (tag: android-10.0-mid-rkr11, tag: android-10.0-mid-rkr10) rochchip: board: only map op-tee share memory as dcache enabled` at least.

If it is printed at the startup stage of Android system, Then upgrade `android/vendor/rockchip/common` version to `8bc7bf97 (tag: android-10.0-mid-rkr10) vpu: librockit: add Rockit MetadataRetriever` at least.

If printing in the startup phase of the Linux system, Then upgrade `linux/external/security/bin` version to `f59085c optee_v1: lib: arm&arm64: update binary and library` at least.

Normally, the versions of Uboot and OP-TEE in released SDK are matched.

3.4.4 U-Boot Run User TA

Some developer need to run their TA in the U-Boot, which can be referred to in this chapter.

1. Confirm if the feature is included. If not, please update the U-Boot code.

```
436fc6d8486 lib: optee_clientApi: support load user ta for optee v1
4d4c5043204 lib: optee_clientApi: add user ta test demo
b122ee17db0 lib: optee_clientApi: support load user ta
deb4d4879d5 lib: optee_clientApi: support pack TA to image
```

2. Developer copy TA files to u-boot/lib/optee_clientApi/userta, This directory supports storing multiple TA files, and by default, rktest TA files are already stored for testing.
3. Execute the following command to package the TA file and generate the userta.img firmware.

```
cd lib/optee_clientApi
./tabinary_to_img.py --tadir ./userta --out ./userta/userta.img
```

4. Modify parameter.txt to add a new userta partition, with a partition size greater than the userta.img firmware size.
5. Use the burning tool to burn parameter.txt and userta.img.
6. U-Boot can call trusty_oem_user_ta_transfer and trusty_oem_user_ta_storage to test rktest ta. Developer can refer to these two functions and call their own TA.

3.5 TEE driver in kernel

TEE kernel driver under `security/optee_linuxdriver/` or `drivers/tee/`

3.5.1 OP-TEE V1

The driver of the chips using OP-TEE V1 is located at `security/optee_linuxdriver/`, All are enabled by default. The method to enable is as follows:

Add the following configurations in config:

```
CONFIG_TEE_SUPPORT=y
```

At present, we will gradually abandon the TEE kernel driver of OP-TEE V1, OP-TEE V1 platform will use the TEE kernel driver of OP-TEE V2.

If version>=v2.00 in the TEE binary file name in the rkbin/bin directory, you also need to enable the TEE kernel driver of OP-TEE V2.

Android 10 and above and Linux released after August 2020 use the TEE kernel driver of OP-TEE V2 by default.

3.5.2 OP-TEE V2

The driver of the chips using OP-TEE V2 is located at `drivers/tee/`, the method to enable is as follows:
Confirm that the following nodes have been added to the platform dtsi file:

```
firmware {
    optee: optee {
        compatible = "linaro,optee-tz";
        method = "smc";
        #status = "disabled";
    };
};
```

This node is added to all platforms by default, However, some platforms will set **status = "disabled"**, Just remove **status = "disabled"** if you want to enable the optee driver.

Add the following two configurations in config:

```
CONFIG_TEE=y
CONFIG_OPTEE=y
```

3.5.3 Confirm TEE drive is enabled

If the `/dev/opteearmtz00` node appears, it indicates that the TEE kernel driver of optee v1 is enabled.
If the `/dev/tee0` and `/dev/teepriv0` node appears, it indicates that the TEE kernel driver of optee v2 is enabled.

3.6 TEE Library

- **Android**

TEE environment components are in the Android project directory `vendor/rockchip/common/security` or `hardware/rockchip/optee`（Including OP-TEE V1 and OP-TEE V2）:

1. lib: Includes tee-supplicant, libteec.so and keymaster/gatekeeper library compiled from 32bit and 64bit platforms.
2. ta: Store the compiled keymaster/gatekeeper TA file.

- **Linux**

TEE environment components are in the Linux project directory `external/security/bin`（Including OP-TEE V1 and OP-TEE V2）:

1. lib: Includes tee-supplicant, libteec.so and other librarys compiled from 32bit and 64bit platforms.
2. ta: Store the compiled TA file.

4. CA/TA Development And Test

4.1 Environment

1. If the compilation reports an error: `No module named Crypto.Signature`, The reason is Python algorithm library is not installed on the development computer, Execute the following command:

   ```
   pip uninstall Crypto
   pip uninstall pycrypto
   pip install pycrypto
   ```

2. If the compilation reports an error: `ModuleNotFoundError: No module named 'Cryptodome'` Please install python package on the development computer: `pip3 install [--user] pycryptodomex`

4.2 CA/TA demo

RK provides a series of CA/TA demo, The purpose is to:

- Provide reference for developers
- Directly used to test TEE environment

The source code of CA/TA demo is in the Android project `external/rk_tee_user`, Or Linux project `external/security/rk_tee_user`.

CA/TA demo contains “rktest” and “xtest”, “xtest” is only available in Android project `external/rk_tee_user/v2`, "xtest" is the open-source test code of OPTEE, Including more complete test items. Generally, if it is used to test TEE environment or reference development, "rktest" can basically meet.

The following describes the functions of rktest.

The CA name of the rktest demo is "rktest", TA named “1db57234-dacd-462d-9bb1ae79de44e2a5.ta” or “1db57234-dacd-462d-9bb1-ae79de44e2a5.ta”.When running the CA program, you need to enter parameters to select the corresponding functions. Enter CA program name+space+any character, The available parameters will be prompted. The test functions implemented by rktest are shown in the following table.

Note: The test program only involves some commonly used functions and does not cover all functions supported by OPTEE.

parameters	function	notes
transfer_data	Test the parameter transfer between CA and TA	
storage	Test the secure storage	Before testing the Secure Storage function, ensure that the corresponding node of the kernel exists, security partition need `/dev/block/by-name/security`; rpmb secure storage need `/dev/block/mmcblk%u`, `/dev/block/mmcblk%urpmb`, `/sys/class/mmc_host/mmc%u/mmc%u:0001/cid`, %u value is any one of 0, 1 and 2; If the node does not exist, please link to the corresponding node.
storage_speed	Test the secure storage speed	
property	Test get property	
crypto_sha	Test SHA algorithm	
crypto_aes	Test AES algorithm	
crypto_rsa	Test RSA encryption and decryption, signature verification	
secstor_ta	Test Built-in TA into secure storage	
otp_read	Test read OEM_S_OTP	The test program hides the otp test item by default, modify /host/rk_test/main.c if you want enable it. OTP characteristics are shown below “OTP Description” chapter.
otp_write	Test write OEM_S_OTP	
otp_size	Get OEM_S_OTP size	
otp_ns_read	Test read OEM_NS_OTP	
otp_ns_write	Test write OEM_NS_OTP	

parameters	function	notes
trng	Get trng data	
socket	Test socket communication between CA and TA	

Execute the test program. The command is as follows:

```
# rktest transfer_data
# rktest [command]
```

The successful execution of CA program prompts PASS, and the failure prompts Fail.

4.3 Android

4.3.1 Directory Introduction

TEE CA/TA development environment locate in Android project directory `external/rk_tee_user`:

1. Android.mk: Decide the compilation tool and the CA file to be compiled.
2. host: CA source files.
3. ta: TA source files.
4. export*: The environment which TA compilation depends on.

4.3.2 Compile

If there are only v1/ v2/ directories under `external/rk_tee_user`, It indicates that the master branch has been merged into the develop-next branch, The master branch will be discarded, Merge point is master branch `492f1cbf testapp: support new OP-TEE MSG`, Execute the following command to start compiling.

```
#For OP-TEE V1 platform
cd external/rk_tee_user/v1
#For OP-TEE V2 platform
cd external/rk_tee_user/v2
rm -rf out/
./build.sh ta
mm
```

If there are no v1/ v2/ directories under `external/rk_tee_user`, It indicates that two branches are still used, please switch to the master branch for OP-TEE V1 platform, please switch to the develop-next branch for OP-TEE V2 platform, Execute the following command to start compiling.

```
cd external/rk_tee_user/
rm -rf out/
./build.sh ta (run if git log contain “Android.mk: remove build ta from android”, otherwise, do not need execute)
mm
```

The execution program will be obtained after successful compilation, The execution program contains CA（Client Application, run on normal world）and TA（Trust Application, run on secure world）.

- CA is a Android execution file, which is generated in the Android project out directory after compilation.
- TA is a file with the file name uuid.ta, Generated in one of the directories rk_tee_user/ta, rk_tee_user/out/ta, rk_tee_user/v1/out/ta, rk_tee_user/v2/out/ta.

4.3.3 Run

1. Enter the device by using adb shell
2. Install TEE library files, CA and TA into the device. For Android 7: push libteec.so into `/system/lib` or `/system/lib64`； push tee-supplicant and CA into /system/bin；create `/system/lib/optee_armtz` directory, push TA into /system/lib/optee_armtz`.

   For Android 8 and later: push libteec.so into `/vendor/lib` or `/vendor/lib64`； push tee-supplicant and CA into `/vendor/bin`； create `/vendor/lib/optee_armtz` directory, push TA into /vendor/lib/optee_armtz`.

   （If tee-supplicant starts automatically after startup, tee-supplicant and libteec.so do not need to push any more. These two files already exist in the system； libteec.so and tee-supplicant should distinguish OP-TEE V1 from OP-TEE V2, Distinguish between 32-bit and 64-bit；

   After push, check whether the tee-supplicant and CA programs have execution permissions.）
3. If the tee-supplicant is not automatically run when the machine is turned on, you need to manually run tee-supplicant in the background with root permission:

   ```
   # tee-supplicant &
   ```

   If print `tee_supp_rk_fs_init: unsupported`, It means security partition is not defined in parameter.txt, Please refer to "parameter.txt" Section for details, If the developer only uses the rpmb or REE file system for secure storage, the error print can be ignored.
4. run CA/TA, test TEE functions. rktest can be used to directly test the basic functions of TEE, execute:

   ```
   # rktest [command]
   ```
5. If rktest run successfully, Then TEE environment is normal, TEE development is available.

   please check the drive and components if error occurs.

   It may also be caused by the mismatch between the rk_tee_user version and the TEE OS version, The following are common matching relationships:

   OP-TEE V1:

version >= v2.00 of TEE binary name under rkbin/bin directory,

match `492f1cbf testapp: support new OP-TEE MSG`

version < v2.00 of TEE binary name under rkbin/bin directory,

match `e8d7215d Android.mk: support build in android R`

or match `466515ec add tools for user to resign TA`

OP-TEE V2:

Serial port printing "OP-TEE version: 3.13.0" during TEE startup, `a566557 - v2: update to keep up with v3.13.0 of optee_test`

Serial port printing "OP-TEE version: 3.6.0" during TEE startup, `1aa969e2 Android.mk: support build in android R`

Serial port printing "OP-TEE version: 3.3.0" during TEE startup, `aa0a0c00 Android.mk: remove build ta from android`

Serial port printing "OP-TEE version: 2.5.0" during TEE startup, `1ec9913a add tools for user to resign TA`

4.3.4 Step By Step

Here is an example of the arm64 platform using OP-TEE V2 on Android 12

```
//Compile CA TA
cd /home1/xxxx/rk_android_12
source build/envsetup.sh
lunch rk3568_s-userdebug
cd /home1/xxxx/rk_android_12/external/rk_tee_user/v2
./build.sh ta
mm

//Push TEE library files and CA TA to devices
adb root && adb remount
adb push Y:\rk_android_12\hardware\rockchip\optee\v2\arm64\libteec.so /vendor/lib64
adb push Y:\rk_android_12\hardware\rockchip\optee\v2\arm64\tee-supplicant /vendor/bin
adb push Y:\rk_android_12\out\target\product\rk3568_s\vendor\bin\rktest /vendor/bin
adb push Y:\rk_android_12\external\rk_tee_user\v2\out\ta\rk_test\1db57234-dacd-462d-9bb1-
ae79de44e2a5.ta /vendor/lib/optee_armtz

//Run CA TA
# tee-supplicant &  //This step can be ignored if tee-supplicant is already running, Android platform is
running by default.
# rktest transfer_data
```

4.3.5 Develop CA/TA

Refer to Makefile about CA TA, the UUID of the header file needs to be modified to a new UUID, It can be generated with the uuidgen command.

head and stack size are defined in user_ta_header_defines.h under include directory, head szie is 32KB（TA_DATA_SIZE）, stack size is 2KB（TA_STACK_SIZE）. Generally, it is better not to modify it. If it cannot meet the needs, it can be appropriately enlarged, The heap size should not exceed 1MB, and the stack size should not exceed 64KB.

```
#define TA_STACK_SIZE          (2 * 1024)
#define TA_DATA_SIZE           (32 * 1024)
```

4.4 Linux

4.4.1 Directory Introduction

TEE CA/TA development environment locate in Linux project directory `external/security/rk_tee_user`:

1. build.sh: Compile script, please refer to the notes in the script for compilation instructions.
2. Makefile: Decide the compilation tool and the CA file to be compiled.
3. host: CA source files.
4. ta: TA source files.
5. export*: The environment which TA compilation depends on.

4.4.2 Compile

If there are only v1/ v2/ directories under `external/security/rk_tee_user`, It indicates that the master branch has been merged into the develop-next branch, The master branch will be discarded, Merge point is master branch `492f1cbf testapp: support new OP-TEE MSG`, Execute the following command to start compiling.

```
#For OP-TEE V1 platform
cd external/security/rk_tee_user/v1
#For OP-TEE V2 platform
cd external/security/rk_tee_user/v2
rm -rf out/
./build.sh 3232  (For 32-bit platform, CA 32bits, TA 32bits)
./build.sh 6432  (For 64-bit platform, CA 64bits, TA 32bits)
```

If there are no v1/ v2/ directories under `external/security/rk_tee_user`, It indicates that two branches are still used, please switch to the master branch for OP-TEE V1 platform, please switch to the develop-next branch for OP-TEE V2 platform, Execute the following command to start compiling.

```
cd external/security/rk_tee_user/
rm -rf out/
./build.sh 3232  (For 32-bit platform, CA 32bits, TA 32bits)
./build.sh 6432  (For 64-bit platform, CA 64bits, TA 32bits)
```

The execution program will be obtained after successful compilation, The execution program contains CA（Client Application, run on normal world）and TA（Trust Application, run on secure world）.

- CA is a Linux execution file, which is generated in one of the directories rk_tee_user/out, rk_tee_user/v1/out, rk_tee_user/v2/out.
- TA is a file with the file name uuid.ta, Generated in one of the directories rk_tee_user/ta, rk_tee_user/out/ta, rk_tee_user/v1/out/ta, rk_tee_user/v2/out/ta.

4.4.3 Run

1. Enter the device by using adb shell.
2. Install TEE library files, CA and TA into the device. push libteec.so* into /lib or /lib64； push tee-supplicant and CA into /usr/bin； create /lib/optee_armtz directory, push TA into /lib/optee_armtz.

   （If tee-supplicant starts automatically after startup, tee-supplicant and libteec.so do not need to push again. These two files already exist in the system； libteec.so and tee-supplicant should distinguish OP-TEE V1 from OP-TEE V2, Distinguish between 32-bit and 64-bit；

   After push, check whether the tee-supplicant and CA programs have execution permissions.）
3. Other steps are the same as Android platform. See the "Android" chapter above.

4.4.4 Step By Step

Here is an example of the arm64 platform using OP-TEE V2 on Linux

```
//Compile CA TA
cd /home1/xxxx/rk_px30_linux/external/security/rk_tee_user/v2
rm -rf out/
./build.sh 6432

//Create optee_armtz directory, it is used to store TA files
# mkdir -p /lib/optee_armtz

//Push TEE library files and CA TA to devices
adb push Y:\rk_px30_linux\external\security\bin\optee_v2\lib\arm64\libteec.so /lib64
adb push Y:\rk_px30_linux\external\security\bin\optee_v2\lib\arm64\libteec.so.1 /lib64
adb push Y:\rk_px30_linux\external\security\bin\optee_v2\lib\arm64\tee-supplicant /usr/bin
adb push Y:\rk_px30_linux\external\security\rk_tee_user\v2\out\rk_test\rktest /usr/bin
adb push Y:\rk_px30_linux\external\security\rk_tee_user\v2\out\ta\rk_test\1db57234-dacd-462d-9bb1-ae79de44e2a5.ta /lib/optee_armtz

//Add executable permissions
# chmod +x /usr/bin/tee-supplicant
# chmod +x /usr/bin/rktest

//Run CA TA
# tee-supplicant &  //this step can be ignored if tee-supplicant is already running
# rktest transfer_data
```

4.4.5 Develop CA/TA

Refer to Makefile about CA TA, the UUID of the header file needs to be modified to a new UUID, It can be generated with the uuidgen command.

head and stack size defined in user_ta_header_defines.h under include directory, head szie is 32KB（TA_DATA_SIZE）, stack size is 2KB（TA_STACK_SIZE）. Generally, it is better not to modify it. If it cannot meet the needs, it can be appropriately enlarged, The heap size should not exceed 1MB, and the stack size should not exceed 64KB.

```
#define TA_STACK_SIZE          (2 * 1024)
#define TA_DATA_SIZE           (32 * 1024)
```

4.5 rk_tee_service

4.5.1 Introduction

rk_tee_service is a security service developed based on TEE, which provides common security functions for developers. The simple and clear external interface greatly facilitates developers' use. rk_tee_service is essentially a CA TA application, Therefore, test the TEE environment is normal before using rk_tee_service.

Developers can directly call rk_ tee_service to encrypts and decrypts sensitive data. The encryption/decryption key is derived by TEE using the unique key HUK inside the device hardware, Therefore, the encryption and decryption keys of each device are different, Copying the sensitive data of device A to device B cannot be decrypted normally to ensure that the sensitive data will not be stolen. Due to the size of shared memory, it is recommended that the size of data encrypted and decrypted at a single time should not exceed 1M. It is recommended to encrypt and decrypt big data in multiple times.

At present, the OP-TEE V2 platform supports this function, while the OP-TEE V1 platform does not.

4.5.2 Component

Currently, it supports Linux platform and Android platform (Android 12 and higher).

Component	Android directory	Linux directory
librk_tee_service.so	hardware/rockchip/optee/v2/arm hardware/rockchip/optee/v2/arm64	external/security/bin/optee_v2/lib/arm external/security/bin/optee_v2/lib/arm64
rk_tee_service.h	hardware/rockchip/optee/v2/include	external/security/bin/optee_v2/include
4367fd45-4469-42a6-925d-3857b952704a.ta	hardware/rockchip/optee/v2/ta	external/security/bin/optee_v2/ta

The Userspace application can directly call librk_tee_service.so, Parameter of function please refer to rk_tee_service.h, Push 4367fd45-4469-42a6-925d-3857b952704a.ta into /lib/optee_armtz for Linux platform , Push 4367fd45-4469-42a6-925d-3857b952704a.ta into /vendor/lib/optee_armtz for Android platform.

4.5.3 Demo

```
#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include "rk_tee_service.h"

int main(int argc, char *argv[])
{
   unsigned char plain[256];
```

```
    unsigned int plain_len;
    unsigned char cipher[256];
    unsigned int cipher_len;
    int res;

    memset((void *)plain, 0xab, sizeof(plain));
    cipher_len = 256;
    res = rk_encrypt_data(plain, sizeof(plain), cipher, &cipher_len);
    printf("res=0x%x cipher_len=%d\n", res, cipher_len);

    memset((void *)plain, 0, sizeof(plain));
    plain_len = 256;
    res = rk_decrypt_data(cipher, cipher_len, plain, &plain_len);
    printf("res=0x%x plain_len=%d\n", res, plain_len);

    return 0;
}
```

4.6 Test xtest

Xtest is an open-source testing code for OPTEE, which includes relatively complete testing items. Customers can refer to this chapter to test xtest.

Here is an example of the arm64 platform using OP-TEE V2 on Android 13:

```
//build CA TA
cd /home1/xxxx/rk_android_13
source build/envsetup.sh
lunch rk3568_t-userdebug
cd /home1/xxxx/rk_android_13/external/rk_tee_user/v2
./build.sh ta
mm

//create plugins directory on device
# mkdir -p /vendor/lib64/tee-supplicant/plugins/

//push TEE library and CA TA to device
adb root && adb remount
adb push Y:\rk_android_13\hardware\rockchip\optee\v2\arm64\libteec.so /vendor/lib64
adb push Y:\rk_android_13\hardware\rockchip\optee\v2\arm64\tee-supplicant /vendor/bin
adb push Y:\rk_android_13\out\target\product\rk3568_t\vendor\bin\xtest /vendor/bin
adb push Y:\rk_android_13\external\rk_tee_user\v2\out\ta\crypt\cb3e5ba0-adf1-11e0-998b-
0002a5d5c51b.ta /vendor/lib/optee_armtz
adb push Y:\rk_android_13\external\rk_tee_user\v2\out\ta\concurrent\e13010e0-2ae1-11e5-896a-
0002a5d5c51b.ta /vendor/lib/optee_armtz
adb push Y:\rk_android_13\external\rk_tee_user\v2\out\ta\create_fail_test\c3f6e2c0-3548-11e1-b86c-
0800200c9a66.ta /vendor/lib/optee_armtz
adb push Y:\rk_android_13\external\rk_tee_user\v2\out\ta\rpc_test\d17f73a0-36ef-11e1-984a-
0002a5d5c51b.ta /vendor/lib/optee_armtz
adb push Y:\rk_android_13\external\rk_tee_user\v2\out\ta\sims\e6a33ed4-562b-463a-bb7e-
ff5e15a493c8.ta /vendor/lib/optee_armtz
adb push Y:\rk_android_13\external\rk_tee_user\v2\out\ta\concurrent_large\5ce0c432-0ab0-40e5-a056-
782ca0e6aba2.ta /vendor/lib/optee_armtz
adb push Y:\rk_android_13\external\rk_tee_user\v2\out\ta\miss\528938ce-fc59-11e8-8eb2-
f2801f1b9fd1.ta /vendor/lib/optee_armtz
```

```
adb push Y:\rk_android_13\external\rk_tee_user\v2\out\ta\socket\873bcd08-c2c3-11e6-a937-d0bf9c45c61c.ta /vendor/lib/optee_armtz
adb push Y:\rk_android_13\external\rk_tee_user\v2\out\ta\sims_keepalive\a4c04d50-f180-11e8-8eb2-f2801f1b9fd1.ta /vendor/lib/optee_armtz
adb push Y:\rk_android_13\external\rk_tee_user\v2\out\ta\os_test\5b9e0e40-2636-11e1-ad9e-0002a5d5c51b.ta /vendor/lib/optee_armtz
adb push Y:\rk_android_13\external\rk_tee_user\v2\out\ta\os_test_lib\ffd2bded-ab7d-4988-95ee-e4962fff7154.ta /vendor/lib/optee_armtz
adb push Y:\rk_android_13\external\rk_tee_user\v2\out\ta\os_test_lib_dl\b3091a65-9751-4784-abf7-0298a7cc35ba.ta /vendor/lib/optee_armtz
//Test storage, The security partition space is limited, which can lead to test failures.
//So delete security partition from parameter.txt, uboot do not define CONFIG_OPTEE_ALWAYS_USE_SECURITY_PARTITION.
//Using the Android file system can pass the test.
adb push Y:\rk_android_13\external\rk_tee_user\v2\out\ta\storage\b689f2a7-8adf-477a-9f99-32e90c0ad0a2.ta /vendor/lib/optee_armtz
adb push Y:\rk_android_13\external\rk_tee_user\v2\out\ta\storage2\731e279e-aafb-4575-a771-38caa6f0cca6.ta /vendor/lib/optee_armtz
adb push Y:\rk_android_13\external\rk_tee_user\v2\out\ta\storage_benchmark\f157cda0-550c-11e5-a6fa-0002a5d5c51b.ta /vendor/lib/optee_armtz
adb push Y:\rk_android_13\external\rk_tee_user\v2\out\ta\supp_plugin\380231ac-fb99-47ad-a689-9e017eb6e78a.ta /vendor/lib/optee_armtz
adb push Y:\rk_android_13\out\target\product\rk3568_t\vendor\lib64\tee-supplicant\plugins\f07bfc66-958c-4a15-99c0-260e4e7375dd.plugin.so /vendor/lib64/tee-supplicant/plugins/
adb push Y:\rk_android_13\hardware\rockchip\optee\v2\arm64\libckteec.so /vendor/lib64
adb push Y:\rk_android_13\external\rk_tee_user\v2\export-ta_arm32\ta\fd02c9da-306c-48c7-a49c-bbd827ae86ee.ta /vendor/lib/optee_armtz

//Run xtest
# tee-supplicant &  //this step can be ignored if tee-supplicant is already running
# xtest
```

Here is an example of the arm64 platform using OP-TEE V2 on Linux:

```
//build CA TA
cd /home1/xxxx/rk_px30_linux/external/security/rk_tee_user/v2
rm -rf out/
./build.sh 6432

//create optee_armtz directory on device
# mkdir -p /lib/optee_armtz
//create plugins directory on device
# mkdir -p /usr/lib/tee-supplicant/plugins/

//push TEE library and CA TA to device
adb push Y:\rk_px30_linux\external\security\bin\optee_v2\lib\arm64\libteec.so /lib64
adb push Y:\rk_px30_linux\external\security\bin\optee_v2\lib\arm64\libteec.so.1 /lib64
adb push Y:\rk_px30_linux\external\security\bin\optee_v2\lib\arm64\tee-supplicant /usr/bin
adb push Y:\rk_px30_linux\external\security\rk_tee_user\v2\out\xtest\xtest /usr/bin
adb push Y:\rk_px30_linux\external\security\rk_tee_user\v2\out\ta\crypt\cb3e5ba0-adf1-11e0-998b-0002a5d5c51b.ta /lib/optee_armtz
adb push Y:\rk_px30_linux\external\security\rk_tee_user\v2\out\ta\concurrent\e13010e0-2ae1-11e5-896a-0002a5d5c51b.ta /lib/optee_armtz
adb push Y:\rk_px30_linux\external\security\rk_tee_user\v2\out\ta\create_fail_test\c3f6e2c0-3548-11e1-b86c-0800200c9a66.ta /lib/optee_armtz
adb push Y:\rk_px30_linux\external\security\rk_tee_user\v2\out\ta\rpc_test\d17f73a0-36ef-11e1-984a-0002a5d5c51b.ta /lib/optee_armtz
```

```
adb push Y:\rk_px30_linux\external\security\rk_tee_user\v2\out\ta\sims\e6a33ed4-562b-463a-bb7e-ff5e15a493c8.ta /lib/optee_armtz
adb push Y:\rk_px30_linux\external\security\rk_tee_user\v2\out\ta\concurrent_large\5ce0c432-0ab0-40e5-a056-782ca0e6aba2.ta /lib/optee_armtz
adb push Y:\rk_px30_linux\external\security\rk_tee_user\v2\out\ta\miss\528938ce-fc59-11e8-8eb2-f2801f1b9fd1.ta /lib/optee_armtz
adb push Y:\rk_px30_linux\external\security\rk_tee_user\v2\out\ta\socket\873bcd08-c2c3-11e6-a937-d0bf9c45c61c.ta /lib/optee_armtz
adb push Y:\rk_px30_linux\external\security\rk_tee_user\v2\out\ta\sims_keepalive\a4c04d50-f180-11e8-8eb2-f2801f1b9fd1.ta /lib/optee_armtz
adb push Y:\rk_px30_linux\external\security\rk_tee_user\v2\out\ta\os_test\5b9e0e40-2636-11e1-ad9e-0002a5d5c51b.ta /lib/optee_armtz
adb push Y:\rk_px30_linux\external\security\rk_tee_user\v2\out\ta\os_test_lib\ffd2bded-ab7d-4988-95ee-e4962fff7154.ta /lib/optee_armtz
adb push Y:\rk_px30_linux\external\security\rk_tee_user\v2\out\ta\os_test_lib_dl\b3091a65-9751-4784-abf7-0298a7cc35ba.ta /lib/optee_armtz
//Test storage, The security partition space is limited, which can lead to test failures.
//So delete security partition from parameter.txt, uboot do not define CONFIG_OPTEE_ALWAYS_USE_SECURITY_PARTITION.
//Using the Android file system can pass the test.
adb push Y:\rk_px30_linux\external\security\rk_tee_user\v2\out\ta\storage\b689f2a7-8adf-477a-9f99-32e90c0ad0a2.ta /lib/optee_armtz
adb push Y:\rk_px30_linux\external\security\rk_tee_user\v2\out\ta\storage2\731e279e-aafb-4575-a771-38caa6f0cca6.ta /lib/optee_armtz
adb push Y:\rk_px30_linux\external\security\rk_tee_user\v2\out\ta\storage_benchmark\f157cda0-550c-11e5-a6fa-0002a5d5c51b.ta /lib/optee_armtz
adb push Y:\rk_px30_linux\external\security\rk_tee_user\v2\out\ta\supp_plugin\380231ac-fb99-47ad-a689-9e017eb6e78a.ta /lib/optee_armtz
adb push Y:\rk_px30_linux\external\security\rk_tee_user\v2\out\supp_plugin\f07bfc66-958c-4a15-99c0-260e4e7375dd.plugin /usr/lib/tee-supplicant/plugins/
adb push Y:\rk_px30_linux\external\security\bin\optee_v2\lib\arm64\libckteec.so.0 /lib64
adb push  Y:\rk_px30_linux\external\security\rk_tee_user\v2\export-ta_arm32\ta\fd02c9da-306c-48c7-a49c-bbd827ae86ee.ta /lib/optee_armtz

//Add executable permissions
# chmod +x /usr/bin/tee-supplicant
# chmod +x /usr/bin/xtest

//Run CA TA
# tee-supplicant &  //this step can be ignored if tee-supplicant is already running
# xtest
```

5. TA Signature

5.1 Principle

When compiling TA, the compile script will automatically use the key in the `export-user_ta/keys` directory or `export-ta_arm32/keys` directory of the rk_tee_user project to sign TA application. The key is 2048 bits RSA key in pem format. Finally, the TA file in .ta format is generated.

There is an RSA public key stored in the TEE binary. When the TA is loaded and run, the TEE OS will use the public key to verify the validity of the TA. Only after the verification is passed, the TA application can run normally.

5.2 Replace the public key

To prevent developer A's TA application from running on developer B's board, it is recommended to replace the public key.

Developers can replace public keys in TEE binary with tools in the rk_tee_user project tools/ directory.

- Linux:

  ```
  ./change_puk --teebin <TEE binary>
  ```

  This command automatically generates a 2048 bits RSA key oemkey.pem in the current directory, and replaces the original public key in the TEE binary with the public key in this key.

  ```
  ./change_puk --teebin <TEE binary> --key oemkey.pem
  ```

  Replace the original public key in the TEE binary with the public key specified by the developer. The key length must be 2048 bits.

- Windows:

  Open Windows_change_puk.exe and click "Generate oemkey.pem" to generate and save keys.

  Select the key and TEE binary you just generated, and click "Modify Public Key".

  (Since Windows_change_puk.exe invokes the BouncyCastle.Crypto.dll third-party library, make sure BouncyCastle.Crypto.dll is in the same directory as Windows_change_puk.exe)

After the public key is replaced, the developer needs to use the new TEE binary to replace the original TEE binary in the rkbin/ directory, recompile the U-Boot, and burn the new `trust.img` firmware. Part of the platforms have no `trust.img` because `trust.img` is packaged into `uboot.img`, so `uboot.img` is burned instead.

The developer needs to rename the key generated or specified by the previous tool to oem_privkey.pem and replace the key in the `export-user_ta/keys` or `export-ta_arm32/keys` directory of the rk_tee_user project. Recompile the CA and TA so that the resulting TA application can be properly loaded and run by the TEE binary (new public key). Any TA that is not signed with the correct private key is considered invalid and cannot be run.

5.3 TA Signature Step By Step

Here is an example of the arm64 platform using OP-TEE V2 on Android 12

```
cd /home1/xxxx/rk_android_12/external/rk_tee_user/v2/tools/change_puk_tool-release/change_puk_linux

chmod +x change_puk

./change_puk --teebin /home1/xxxx/rk_android_12/rkbin/bin/rk35/rk3588_bl32_v1.17.bin

cp oem_privkey.pem /home1/xxxx/rk_android_12/external/rk_tee_user/v2/export-ta_arm32/keys/

cp oem_privkey.pem /home1/xxxx/rk_android_12/external/rk_tee_user/v2/export-ta_arm64/keys/

//Recompile and burn the uboot firmware, recompile the CA TA application
```

6. Built-in TA into secure storage

In normal cases, TA files are stored in plaintext in an non-secure file system after TA development. Some OEM that have high security requirements do not want TA files to be exposed in plaintext. To meet the OEM' requirements, OP-TEE V2 supports built-in TA files to secure storage (OP-TEE V1 does not support this).

6.1 Principle

The CA side reads TA files in the non-secure file system and sends TA data to the OP-TEE OS. After receiving TA data, the OP-TEE OS verifies the validity of TA. If TA is legal, it randomly generates TA encryption key and encrypts TA data with TA encryption key. Then the ciphertext TA data and TA encryption key are securely stored (If security partition is defined, it is stored in the security partition; if not defined, it is stored in the Android or Linux file system). The key used for secure storage is derived from the unique key of the hardware, which is different for each device. Finally, the developer needs to delete TA files in the non-secure file system to prevent the plaintext TA from being exposed.

After the appeal step is complete, the CA can call the TA application normally. When the CA calls the TA in the secure storage, the OP-TEE OS searches for the TA in the secure storage according to the incoming uuid. If the TA is found, the OP-TEE OS decrypts and loads the TA; if the TA is not found in secure storage, the TA will be searched in the non-secure file system.

6.2 Reference implementation

Here is the CA-side code that lets you read the TA file and send the TA data to the OP-TEE OS using the `install_ta` function.

```
static void install_ta(void *buf, size_t blen)
{
  TEEC_Result res = TEEC_ERROR_GENERIC;
  uint32_t err_origin = 0;
  TEEC_UUID uuid = PTA_SECSTOR_TA_MGMT_UUID;
  TEEC_Operation op;
  TEEC_Context ctx = { };
```

```
    TEEC_Session sess = { };
    int i = 0;

    res = TEEC_InitializeContext(NULL, &ctx);
    if (res != TEEC_SUCCESS) {
        printf("TEEC_InitializeContext failed with code 0x%x\n", res);
        goto exit;
    }

    res = TEEC_OpenSession(&ctx, &sess, &uuid,
                TEEC_LOGIN_PUBLIC, NULL, NULL, &err_origin);
    if (res != TEEC_SUCCESS) {
        printf("TEEC_Opensession failed with code 0x%x origin 0x%x\n",
            res, err_origin);
        goto exit;
    }

    memset(&op, 0, sizeof(op));
    op.paramTypes = TEEC_PARAM_TYPES(TEEC_MEMREF_TEMP_INPUT, TEEC_NONE,
                TEEC_NONE, TEEC_NONE);
    op.params[0].tmpref.buffer = buf;
    op.params[0].tmpref.size = blen;


    res = TEEC_InvokeCommand(&sess, PTA_SECSTOR_TA_MGMT_BOOTSTRAP, &op,
              &err_origin);
    if (res != TEEC_SUCCESS) {
        printf("TEEC_InvokeCommand failed with code 0x%x origin 0x%x\n",
            res, err_origin);
        goto exit;
    }
    printf("Installing TAs done\n");

exit:
    TEEC_CloseSession(&sess);
    TEEC_FinalizeContext(&ctx);

    return;
}
```

7. Encrypt TA

Section in the previous chapter Built-in TA to secure storage introduce one way to avoid exposing clear TA file, but the built-in TA will take up secure storage space, If the secure storage data is abnormal, the built-in TA cannot be used, and TA's secret key is randomly generated, not the developers own encryption key, this chapter introduces another kind of encryption method of TA (OP - TEE V2 support, OP-TEE V1 is not currently supported).

7.1 Method of encrypting TA

If the developer has TA source code, the developer needs to enable the `CFG_ENCRYPT_TA` macro in `export-ta_arm32/mk/link.mk` and change `TA_ENC_KEY` to developer's own encryption key. After this macro is enabled, the script will automatically sign and encrypt TA when the developer compiles TA application.

If the developer does not have TA source code and only has TA binary files, they can use tools to encrypt the TA binary files. The required tools can be found in the rk_tee_user project tools/ directory.

Command to encrypt plaintext TA:

```
python3 ta_encrypt_tool.py --key oem_privkey.pem --in 1db57234-dacd-462d-9bb1-ae79de44e2a5.ta --enc_key 'b64d239b1f3c7d3b06506229cd8ff7c8af2bb4db2168621ac62c84948468c4f4'
```

Command to re-encrypt ciphertext TA:

```
python3 ta_encrypt_tool.py --key oem_privkey.pem --in 1db57234-dacd-462d-9bb1-ae79de44e2a5.ta --ori_enc_key 'b64d239b1f3c7d3b06506229cd8ff7c8af2bb4db2168621ac62c84948468c4f4' --enc_key 'c74d239b1f3c7d3b06506229cd8ff7c8af2bb4db2168621ac62c84948468c4f4'
```

Tool parameter description:

--key Point to the user's private asymmetric key file used for signing TA.

--in Point to TA file.

--enc_key The user's private symmetric key used to encrypt TA.

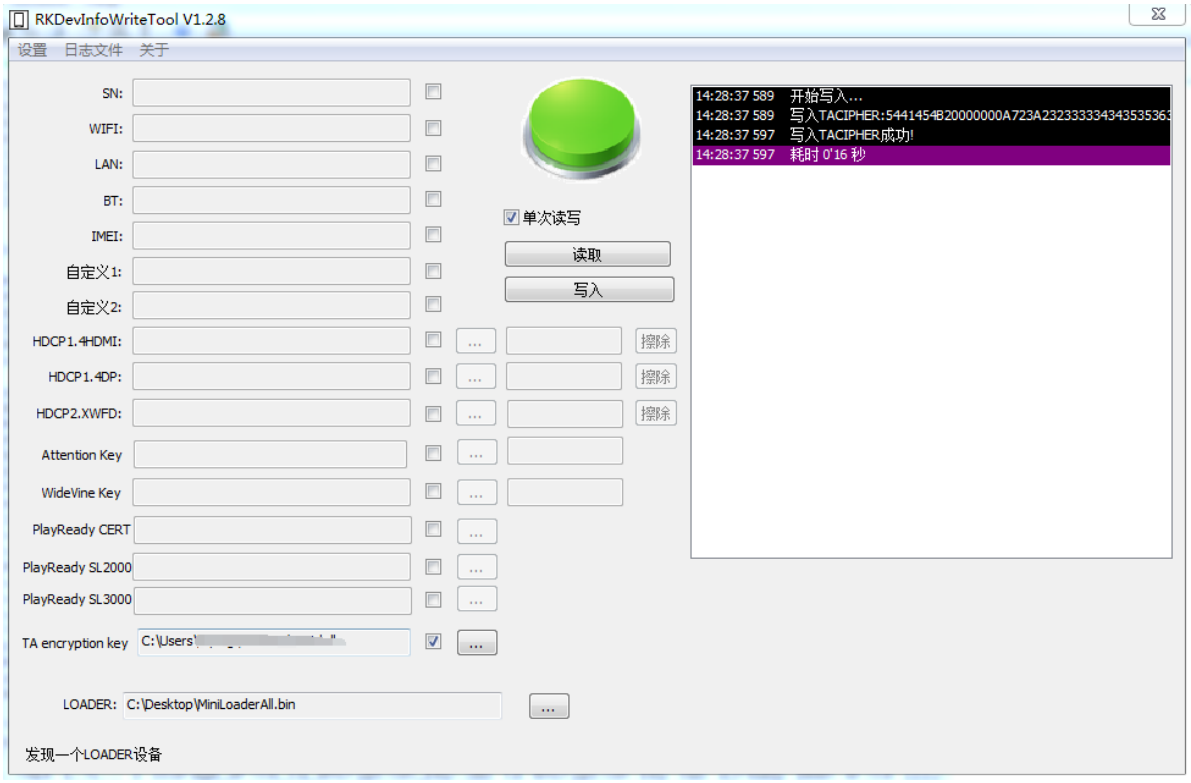
--ori_enc_key The original symmetric key used to encrypt TA.

7.2 Burn TA encryption key

The developer uses the `RKDevInfoWriteTool` tool (version no less than 1.2.8) in the RKTools directory of the SDK project to write TA encryption key.

Before use, the developer needs to create a new key file, open the file in hexadecimal format, edit the developer's 32-byte encryption key in the file, open the RKDevInfoWriteTool tool, select "TA encryption key", and click the button to select the key file created by the developer. After the device enters the LOADER mode, click the "Write" ("写入") button to write the key. The key will be written to the device OTP (the OTP area cannot be changed once written, so the key can only be written once on device).

To prevent TA encryption key disclosure, the tool does not support reading TA encryption key.



7.3 Decrypt and run the TA

The use of encrypted TA and plaintext TA is exactly the same. OP-TEE OS will automatically recognize that TA is encrypted when loading TA, and OP-TEE OS will automatically read TA encryption key in OTP and decrypt and run TA. This process is automatically completed by OP-TEE OS.

7.4 Soft TA encryption key

If developers do not want to add extra steps to burn the TA encryption key to the device OTP, they can use the Soft TA encryption key, which is a symmetric key built into the TEE binary.

If the developer has burned the TA encryption key to the device OTP, the OP-TEE OS will prioritize using the TA encryption key in the OTP to decrypt and run the TA, ensuring high security.

If the developer does not burn the TA encryption key to the device OTP, the OP-TEE OS will use the Soft TA encryption key to decrypt and run the TA, resulting in lower security.

Developers need to use tools to replace the Soft TA encryption key in the TEE binary. The required tools can be found in the rk_tee_user project tools/ directory.

Command to replace the default Soft TA encryption key in TEE binary:

```
./change_ta_enc_key --teebin <TEE binary> --takey
'b64d239b1f3c7d3b06506229cd8ff7c8af2bb4db2168621ac62c84948468c4f4'
```

Tool parameter description:

--teebin Provide the TEE binary firmware path.

--takey 32 bytes private key for developers, which must be consistent with the key used to encrypt TA.

8. REE FS TA anti-rollback

As shown in Built-in TA to secure storage , OP-TEE V2 supports storing TA in both REE FS and Secure storage in plain text. OP-TEE V2 supports TA rollback prevention if TA is stored in plain text in REE FS, preventing TA version rollback in an REE non-secure environment.

8.1 TA anti-rollback usage

The TA anti-rollback function of REE FS is always enabled. Developers can use the anti-rollback function by defining the TA version number in the Makefile.

If `CFG_TA_VERSION` is never defined in TA's Makefile, the system recognizes TA's version number as 0 and allows TA with the same version number to run.

If the Makefile of TA defines that the current `CFG_TA_VERSION` is greater than 0, as shown in the following example, the rollback of TA version is prevented.

```
# unsigned integer format
CFG_TA_VERSION=1
```

9. TA debugging methods

9.1 OP-TEE v1 platforms

When TA encounters a serious error condition, it prints diagnostic information as follows.

```
user TA data-abort at address 0x2a

 esr 0x92000021  ttbr0 0x400000852fc00   ttbr1 0x00000000   cidr 0x0

 cpu #4        cpsr 0x20000130

#For 32-bit platforms, print r0-r12, sp, lr, pc(402000a0)
#For 64-bit platforms, print x0-x30, sp_el0, elr(00000000402000a0)

Status of TA 8cccf200-2450-11e4-abe20002a5d5c52c (0x85109b0) (active)
- load addr : 0x40200000    ctx-idr: 4
- code area : 0x9200000 2097152
- stack: 0x9400000 stack:2048
TEEC_InvokeCommand failed with code 0xffff3024 origin 0x3
```

The `pc` or `elr` in the error condition is the virtual address that caused the exception. The `load addr` is the virtual address of the TA running in memory. We can konw the offset of the exception code in the TA is, elr - load addr = 0x402000a0 - 0x40200000 = 0xa0.

In the compiled directory, there is a file named by `uuid.dmp` in the same directory as the TA. The `uuid.dmp` is a disassembly file of the TA, which identifies the offset address of each function in the TA. Search for `a0` in the `uuid.dmp`, as follows, where `testapp_ta.c:97` indicates that the exception code is on line 97 of `testapp_ta.c`.

```
/home/xxx/android/vendor/optee_test/ta/testapp/testapp_ta.c:97
   98:  6823      ldr r3, [r4, #0]
   9a:  2202      movs    r2, #2
   9c:  2161      movs    r1, #97 ; 0x61
   9e:  4820      ldr r0, [pc, #128]  ; (120 <TA_InvokeCommandEntryPoint+0xa0>)
   a0:  681b      ldr r3, [r3, #0]
   a2:  4478      add r0, pc
   a4:  3033      adds    r0, #51 ; 0x33
   a6:  9301      str r3, [sp, #4]
   a8:  4b1e      ldr r3, [pc, #120]  ; (124 <TA_InvokeCommandEntryPoint+0xa4>)
   aa:  447b      add r3, pc
   ac:  9300      str r3, [sp, #0]
   ae:  2301      movs    r3, #1
   b0:  f002 fbc0   bl  2834 <trace_printf>
```

9.2 OP-TEE v2 platforms

When TA encounters a serious error condition, it prints diagnostic information as follows.

```
E/TC:? 0 User mode data-abort at address 0x2a (translation fault)
E/TC:? 0  esr 0x92000005  ttbr0 0x20000084a7020   ttbr1 0x00000000   cidr 0x0
E/TC:? 0  cpu #1        cpsr 0x20000130

#For 32-bit platforms, print r0-r12, sp, lr, pc(c00870a4)
#For 64-bit platforms, print x0-x30, sp_el0, elr(00000000c00870a4)

E/LD:  region  0: va 0xc0004000 pa 0x08600000 size 0x002000 flags rw-s (ldelf)
E/LD:  region  1: va 0xc0006000 pa 0x08602000 size 0x008000 flags r-xs (ldelf)
E/LD:  region  2: va 0xc000e000 pa 0x0860a000 size 0x001000 flags rw-s (ldelf)
E/LD:  region  3: va 0xc000f000 pa 0x0860b000 size 0x004000 flags rw-s (ldelf)
E/LD:  region  4: va 0xc0013000 pa 0x0860f000 size 0x001000 flags r--s
E/LD:  region  5: va 0xc0014000 pa 0x08625000 size 0x001000 flags rw-s (stack)
E/LD:  region  6: va 0xc0015000 pa 0x09201000 size 0x002000 flags rw-- (param)
E/LD:  region  7: va 0xc0087000 pa 0x00001000 size 0x009000 flags r-xs [0]
E/LD:  region  8: va 0xc0090000 pa 0x0000a000 size 0x00c000 flags rw-s [0]
E/LD:   [0] 8cccf200-2450-11e4-abe2-0002a5d5c52c @ 0xc0087000
E/LD:  Call stack:
E/LD:   0xc00870a4
E/LD:   0xc0088b21
E/LD:   0xc008d507
E/LD:   0xc008716c
```

The `pc` or `elr` in the error condition is the virtual address that caused the exception. The `region 0 - region 8` are the virtual address of the TA code running in memory. The exception code address `0xc00870a4` is in `region 7`. We can calculate the offset of the exception code as following, elr - region 7 : va = 0xc00870a4 - 0xc0087000 = 0xa4.

In the compiled directory, there is a file named by uuid.dmp in the same directory as the TA. The `uuid.dmp` is a disassembly file of the TA, which identifies the offset address of each function in the TA. Search for `a4` in the `uuid.dmp`, as follows, where `testapp_ta.c:101` indicates that the exception code is on line 101 of `testapp_ta.c`.

```
/home/xxx/rk_px30_linux/external/optee_test/ta/testapp/testapp_ta.c:101
    9c:  6823      ldr r3, [r4, #0]
    9e:  2202      movs    r2, #2
    a0:  4d28      ldr r5, [pc, #160]  ; (144 <TA_InvokeCommandEntryPoint+0xc4>)
    a2:  4e29      ldr r6, [pc, #164]  ; (148 <TA_InvokeCommandEntryPoint+0xc8>)
    a4:  681b      ldr r3, [r3, #0]
    a6:  447d      add r5, pc
    a8:  447e      add r6, pc
    aa:  3533      adds    r5, #51 ; 0x33
    ac:  4628      mov r0, r5
    ae:  9600      str r6, [sp, #0]
    b0:  9301      str r3, [sp, #4]
    b2:  2301      movs    r3, #1
    b4:  f000 f912   bl  2dc <trace_printf>
```

9.3 Call stack

If the exception code address is not enough for you and also need functions call stack, the script `export-ta_arm32\scripts\symbolize.py` in OP-TEE v2 provides to show call stack. Note that the OP-TEE v1 platform does not support the script.

Step 1, set the compiler path you are using.

```
#For 32-bit platforms, execute:
export PATH=/home1/hisping/rk_px30_linux/prebuilts/gcc/linux-x86/arm/gcc-linaro-6.3.1-2017.05-x86_64_arm-linux-gnueabihf/bin:$PATH
export CROSS_COMPILE=arm-linux-gnueabihf-

#For 64-bit platforms, execute:
export PATH=/home1/hisping/rk_px30_linux/prebuilts/gcc/linux-x86/aarch64/gcc-linaro-6.3.1-2017.05-x86_64_aarch64-linux-gnu/bin:$PATH
export CROSS_COMPILE=aarch64-linux-gnu-
```

Step 2, execute the script and `-d` parameter points to the TA compiled directory.

```
./export-ta_arm32/scripts/symbolize.py -d out/ta/testapp/
```

Step 3, the script will wait for the exception log, after input, you can get the following result including `Call stack`.

```
I/TA: Hello Test App!
E/TC:? 0
E/TC:? 0 User mode data-abort at address 0x2a (translation fault)
E/TC:? 0  esr 0x92000005  ttbr0 0x20000084a7020   ttbr1 0x00000000   cidr 0x0
E/TC:? 0  cpu #1        cpsr 0x20000130
E/TC:? 0  x0  00000000000069ee x1  0000000000000062
E/TC:? 0  x2  0000000000000002 x3  000000000000002a
E/TC:? 0  x4  00000000c0014f30 x5  00000000c0014f40
```

```
E/TC:? 0  x6  00000000c0074080 x7  00000000c0074308
E/TC:? 0  x8  00000000c00742e8 x9  00000000c0014f30
E/TC:? 0  x10 0000000000000065 x11 00000000c007f2d8
E/TC:? 0  x12 0000000000000773 x13 00000000c0014f00
E/TC:? 0  x14 00000000c006cb0d x15 0000000000000000
E/TC:? 0  x16 0000000000000000 x17 0000000000000000
E/TC:? 0  x18 0000000000000000 x19 0000000000000000
E/TC:? 0  x20 0000000000000000 x21 0000000000000000
E/TC:? 0  x22 0000000000000000 x23 0000000000000000
E/TC:? 0  x24 0000000000000000 x25 0000000000000000
E/TC:? 0  x26 0000000000000000 x27 0000000000000000
E/TC:? 0  x28 0000000000000000 x29 0000000000000000
E/TC:? 0  x30 0000000000000000 elr 00000000c006b0a4
E/TC:? 0  sp_el0 00000000c0014f80
E/LD:  Status of TA 8cccf200-2450-11e4-abe2-0002a5d5c52c
E/LD:   arch: arm
E/LD:  region  0: va 0xc0004000 pa 0x08600000 size 0x002000 flags rw-s (ldelf)
E/LD:  region  1: va 0xc0006000 pa 0x08602000 size 0x008000 flags r-xs (ldelf)
E/LD:  region  2: va 0xc000e000 pa 0x0860a000 size 0x001000 flags rw-s (ldelf)
E/LD:  region  3: va 0xc000f000 pa 0x0860b000 size 0x004000 flags rw-s (ldelf)
E/LD:  region  4: va 0xc0013000 pa 0x0860f000 size 0x001000 flags r--s
E/LD:  region  5: va 0xc0014000 pa 0x08625000 size 0x001000 flags rw-s (stack)
E/LD:  region  6: va 0xc0015000 pa 0x09201000 size 0x002000 flags rw-- (param)
E/LD:  region  7: va 0xc006b000 pa 0x00001000 size 0x009000 flags r-xs [0] .ta_head .text .rodata
.ARM.extab .ARM.exidx .dynsym .dynstr .hash
E/LD:  region  8: va 0xc0074000 pa 0x0000a000 size 0x00c000 flags rw-s [0] .dynamic .got .rel.got .data .bss
.rel.dyn
E/LD:   [0] 8cccf200-2450-11e4-abe2-0002a5d5c52c @ 0xc006b000 (out/ta/testapp/8cccf200-2450-11e4-
abe2-0002a5d5c52c.elf)
E/LD:  Call stack:
E/LD:   0xc006b0a4 TA_InvokeCommandEntryPoint at ta/testapp/testapp_ta.c:98
E/LD:   0xc006cb0d entry_invoke_command at
/home/zhangzj/secure/optee_3.6.0/optee_os/lib/libutee/arch/arm/user_ta_entry.c:357
E/LD:   0xc00714f3 __ta_entry_c at export-ta_arm32/src/user_ta_header.c:48
E/LD:   0xc006b158 __ta_entry at export-ta_arm32/src/ta_entry_a32.S:20
```

10. Memory description

10.1 OP-TEE V1

platform	TEE_RAM	TA_RAM	SHMEM
RK312x	1M	12M	1M
RK322x	1M	12M	2M
RK3288	1M	12M	2M
RK3368	2M	24M	4M
RK3328/RK322xH	2M	24M	4M
RK3399/RK3399Pro	2M	24M	4M

Note: The secure OS runs in TEE_RAM. The TA runs in TA_RAM. SHMEM is the shared memory.

10.2 OP-TEE V2

platform	TEE_RAM	TA_RAM	SHMEM
RK3326/PX30	2M	4M	2M
RK3358	2M	4M	2M
RK3308	2M	1M	1M
RK1808	2M	1M	1M
RV1109/RV1126	760K	1M	512K
RK3566/RK3568	2M	12M	2M
RK3588	2M	12M	2M
RK3528	2M	4M	2M
RK3562	2M	4M	2M
RV1106	1M	1M	512K

Note: The secure OS runs in TEE_RAM. The TA runs in TA_RAM. SHMEM is the shared memory.

OP-TEE OS supports printing secure memory info, and developers can view the following information in the startup log.

```
I/TC: OP-TEE memory: TEEOS 0x200000 TA 0xc00000 SHM 0x200000
I/TC: Primary CPU initializing
I/TC: Primary CPU switching to normal world boot
```

If the size of the startup log printing does not match the above list, the printing shall prevail.

11. Secure Storage

11.1 Partition

1. Secure storage is one of the important functions of OP-TEE OS. It generally used to store private user data. Data is encrypted by OP-TEE OS and then stored in the security partition or rpmb partition or Android/Linux file system.

   There are three types of TEE secure storage:

   The first, set storageID=TEE_STORAGE_PRIVATE_RPMB in TA code, then emmc rpmb is used for secure storage. The rpmb size varies for each emmc model, typically 4M.

The second, define security partition in parameter.txt and set storageID=TEE_STORAGE_PRIVATE_REE in TA code, then secure storage is stored in the security partition, which is currently available at 512k.

The third, there is no security partition defined in parameter.txt and set storageID=TEE_STORAGE_PRIVATE_REE in TA code, then secure storage is stored in the Android/Linux file system /metadata/tee or /data/vendor/tee or /data/tee directory (please confirm that tee-supplicant has permission to access this directory), and the total space is not limited. The disadvantage is that the device needs to use emmc and uboot cannot define CONFIG_OPTEE_ALWAYS_USE_SECURITY_PARTITION, The security data in the uboot stage should be stored in the EMMC rpmb by default.

2. Secure storage on the Uboot side, please refer to the "TEE Driver in U-Boot" section.
3. Make sure that the device does not power down when writing data for secure storage. The reason is that although we have done power loss protection but do not ensure the integrity of file system. Therefore, it is recommended that developers reduce the number of writes to ensure data security. In theory, RPMB provides better power off protection than security and Android/Linux file systems.

11.2 Performance testing

Test environment: OP-TEE V1, RK3399 in Linux platform, CPU fixed frequency to 1200000, DDR fixed frequency to 200000000.

Storage area	Data size	Create an empty file	Write	Read	Delete the file
Linux file system	30K	16ms	67ms	61ms	19ms
Linux file system	4K	17ms	23ms	13ms	7ms
Linux file system	1K	18ms	16ms	7ms	6ms
Linux file system	32	23ms	16ms	7ms	7ms
security partition	30K	97ms	181ms	54ms	277ms
security partition	4K	101ms	74ms	14ms	101ms
security partition	1K	104ms	56ms	7ms	64ms
security partition	32	103ms	55ms	7ms	73ms
rpmb partition	30K	20ms	233ms	10ms	7ms
rpmb partition	4K	20ms	36ms	3ms	6ms
rpmb partition	1K	22ms	14ms	2ms	6ms
rpmb partition	32	27ms	8ms	2ms	6ms

Test environment: OP-TEE V2, RK356x in Linux platform, CPU fixed frequency to 1416000, DDR fixed frequency to 324000000.

Storage area	Data size	Create an empty file	Write	Read	Delete the file
Linux file system	30K	17ms	28ms	3ms	8ms
Linux file system	4K	17ms	11ms	1ms	8ms
Linux file system	1K	18ms	9ms	1ms	8ms
Linux file system	32	19ms	8ms	1ms	7ms
security partition	30K	12ms	12ms	4ms	12ms
security partition	4K	12ms	3ms	1ms	11ms
security partition	1K	13ms	2ms	1ms	11ms
security partition	32	15ms	3ms	1ms	14ms
rpmb partition	30K	23ms	287ms	16ms	5ms
rpmb partition	4K	24ms	50ms	7ms	6ms
rpmb partition	1K	23ms	22ms	5ms	6ms
rpmb partition	32	30ms	12ms	5ms	5ms

12. Solution of optional strong or weak security levels

12.1 Scope

Solution applies to: RK3588, RK3528, RK3562 and subsequent new platforms.

12.2 Notes

Before using this solution, you should be aware of the following.

- Before downloading the firmware for the first time, confirm that the configuration items of uboot `CONFIG_OPTEE_SECURITY_LEVEL` configured as required. It only supports configuration once and cannot be modified later. The SDK is security level 0 as defaults. If the development board has already burned the leve0 firmware, burning the leve1 or level 2 firmware may not

start properly. Therefore, it is recommended to test with a new device after changing the `CONFIG_OPTEE_SECURITY_LEVEL` .
- If you select "Strong Security Solution 1", download the OEM HUK using the tool `RKDevInfoWriteTool (V1.3.5 and above)` before using.

12.3 Solution description

The solution supports the configuration of the security level of OP-TEE by the developer, and the protection strength of eMMC/Secure Storage is different for each security levels.

Security level	**Description**	**CONFIG_OPTEE_SECURITY_LEVEL (uboot's configuration item)**
Strong Security Solution 2	CPU chip and eMMC/secure storage data are strongly bound, if the CPU chip is replaced, you should replace a new eMMC chip and erase securely stored data.	2
Strong Security Solution 1	CPU chip and eMMC/secure storage data are weakly bound, the OEM HUK which derives for protecting eMMC/secure storage is defined by developer, if you download the same OEM HUK after replacing the CPU chip, then you can use the original eMMC/secure storage data.	1
Weak Security Solution	CPU chip and eMMC/secure storage data are not bound, you can use the original eMMC/secure storage data after replacing the CPU chip.	0 or none

The difference between the above security levels is due to the difference between eMMC and Secure Storage related keys. The keys related to this solution are described below.

- HUK: for deriving RPMB Key, Secure Storage Key and other keys. Different HUK for different security levels. See figures below for details.
  Hard HUK is derived from the Device Root Key. Unique key in chips. Device Root Key was burned into secure OTP when chip is manufactured.
  OEM HUK is defined by developer and burned into secure OTP by developer.
  Soft HUK is defined by Rockchip and all chips have the same soft HUK. It is stored in firmware.
- RPMB Key: the storage protection key of the eMMC chip.
- Secure Storage Key: the key for secure storage.
- Other Key: other keys used in OP-TEE.

```
Strong Security Solution 2

                    /------> RPMB Key
```

```
Device Root Key ---> Hard HUK ------> Secure Storage Key
                        \------> Other Key

Strong Security Solution 1

Device Root Key ---> Hard HUK ------> Other Key

                /------> RPMB Key
OEM HUK ----------------
                \------> Secure Storage Key


Weak Security Solution

Device Root Key ---> Hard HUK ------> Other Key

                /------> RPMB Key
Soft HUK ----------------
                \------> Secure Storage Key
```

13. OTP description

OTP is One Time Programmable Memory. The OTP region supports multiple reads but only written once.

Multiple different OEM Zone areas are reserved in Secure OTP to meet users' different usage needs.

OTP type	Description	supported platforms
OEM Cipher Key	This OEM Zone area is used to store user keys. Once the key is written, it cannot be changed. After the user burns the key, they can use the specified key for encryption and decryption operations.	rv1126, rv1109, rk3566, rk3568, rk3588, rk3528, rk3562, rv1106
Protected OEM Zone	This OEM Zone area is only available for Trust Application (TA application) calls running on OP-TEE OS, and cannot be directly read or written to in non secure world. Please refer to rktest demo.	rk3308, rk3326, rk3358, rk3566, rk3568, rk3588, rv1126, rv1109, rk3528, rk3562, rv1106
Non-Protected OEM Zone	This OEM Zone area can be called by U-Boot and UserSpace, and the data will be exposed in non secure world memory.	rk3308, rk3326, rk3358, rk3566, rk3568, rk3588, rv1106, rk3528, rk3562

For more details, please refer to the document "Rockchip_Developer_Guide_OTP_EN.pdf"

14. TA API description

14.1 Overview

RK provides the following TA APIs for two purposes:

- For developers to refer to how to use the GlobalPlatform TEE Internal Core APIs
- For developers to use the APIs directly

14.2 API return value

The return value of APIs are:

- TEE_SUCCESS: if the function executes successfully
- TEE_ERROR_BAD_PARAMETERS: if the parameter is wrong
- Others: see `tee_api_defines.h`

14.3 API description

14.3.1 Crypto API

14.3.1.1 rk_crypto_malloc_ctx

```
crypto_ctx_t *rk_crypto_malloc_ctx(void);
```

Description

Request a crypto operation handle resource.

Parameters

- None.

14.3.1.2 rk_crypto_free_ctx

```
void rk_crypto_free_ctx(crypto_ctx_t **ctx);
```

Description

Release the crypto operation handle. It should be executed to release resources after algorithm is done.

Parameters

- ctx: crypto context

14.3.1.3 rk_hash_crypto

```
TEE_Result rk_hash_crypto(uint8_t *in, uint8_t *out, uint32_t in_len,
                          uint32_t out_len, uint32_t algo);
```

Description

The hash digest algorithm. If you need to input message multiple times, you can use the `rk_hash_begin/update/finish` interface.

Parameters

- in: input data
- in_len: the length of input
- out: output data
- out_len: the length of output
- algo: algorithm type, supports `TEE_ALG_MD5`, `TEE_ALG_SHA1`, `TEE_ALG_SHA224`, `TEE_ALG_SHA256`, `TEE_ALG_SHA384`, `TEE_ALG_SHA512`

14.3.1.4 rk_hash_begin

```
TEE_Result rk_hash_begin(crypto_ctx_t *ctx, uint32_t algo);
```

Description

The hash digest algorithm for multiple, initialization operation.

Parameters

- ctx: crypto context
- algo: algorithm type, supports `TEE_ALG_MD5`, `TEE_ALG_SHA1`, `TEE_ALG_SHA224`, `TEE_ALG_SHA256`, `TEE_ALG_SHA384`, `TEE_ALG_SHA512`

14.3.1.5 rk_hash_update

```
TEE_Result rk_hash_update(crypto_ctx_t *ctx, uint8_t *in, uint32_t in_len);
```

Description

The hash digest algorithm for multiple, calculates digest of the data inputed.

Parameters

- ctx: crypto context
- in: input data
- in_len: the length of input

14.3.1.6 rk_hash_finish

```
TEE_Result rk_hash_finish(crypto_ctx_t *ctx, uint8_t *in, uint8_t *out,
                          uint32_t in_len, uint32_t *out_len);
```

Description

The hash digest algorithm for multiple, calculates the digest of the last part and output the digest.

Parameters

- ctx: crypto context
- in: input data
- in_len: the length of input
- out: output data
- out_len: the length of output

14.3.1.7 rk_cipher_crypto

```
TEE_Result rk_cipher_crypto(uint8_t *in, uint8_t *out, uint32_t len,
                            uint8_t *key, uint32_t key_len, uint8_t *iv,
                            uint32_t algo, TEE_OperationMode mode);
```

Description

Symmetric encryption/decryption algorithm interface. If you need to input data multiple times, you can use the `rk_cipher_begin/update/finish` interface.

Parameters

- in: input data
- len: the length of input
- out: output data
- key: the key used for cipher
- key_len: the length of key, different algo may supports different key lengths
- iv: initialization vector
- algo: algorithm type, support the following(OP-TEE V1 dose not support the SM algorithm)

  ```
  TEE_ALG_AES_ECB_NOPAD
  TEE_ALG_AES_CBC_NOPAD
  TEE_ALG_AES_CTR
  TEE_ALG_AES_CTS
  TEE_ALG_AES_XTS
  TEE_ALG_SM4_ECB_NOPAD
  TEE_ALG_SM4_CBC_NOPAD
  TEE_ALG_SM4_CTR
  TEE_ALG_DES_ECB_NOPAD
  TEE_ALG_DES_CBC_NOPAD
  TEE_ALG_DES3_ECB_NOPAD
  TEE_ALG_DES3_CBC_NOPAD
  ```

- mode: the mode of cipher

14.3.1.8 rk_set_padding

```
TEE_Result rk_set_padding(crypto_ctx_t *ctx, int padding);
```

Description

Sets the padding mode for encrypted/decrypted data.

Parameters

- ctx: crypto context
- padding: see `rk_padding_t` for supported modes

14.3.1.9 rk_cipher_begin

```
TEE_Result rk_cipher_begin(crypto_ctx_t *ctx, uint8_t *key, uint32_t key_len,
                           uint8_t *iv, uint32_t algo, TEE_OperationMode mode);
```

Description

The initialization operation of the symmetric encryption/decryption algorithm for multiple.

Parameters

- ctx: crypto context
- key: the key used for cipher
- key_len: the length of key, different algo may supports different key lengths
- iv: initialization vector
- algo: algorithm type, support the following(OP-TEE V1 dose not support the SM algorithm)

  ```
  TEE_ALG_AES_ECB_NOPAD
  TEE_ALG_AES_CBC_NOPAD
  TEE_ALG_AES_CTR
  TEE_ALG_AES_CTS
  TEE_ALG_AES_XTS
  TEE_ALG_SM4_ECB_NOPAD
  TEE_ALG_SM4_CBC_NOPAD
  TEE_ALG_SM4_CTR
  TEE_ALG_DES_ECB_NOPAD
  TEE_ALG_DES_CBC_NOPAD
  TEE_ALG_DES3_ECB_NOPAD
  TEE_ALG_DES3_CBC_NOPAD
  ```

- mode: the mode of cipher

14.3.1.10 rk_cipher_update

```
TEE_Result rk_cipher_update(crypto_ctx_t *ctx, uint8_t *in, uint8_t *out,
                            uint32_t in_len, uint32_t *out_len);
```

Description

Encrypt/decrypt the input data of symmetric encryption/decryption algorithm for multiple.

Parameters

- ctx: crypto context
- in: input data
- in_len: the length of input
- out: output data
- out_len: the length of output

14.3.1.11 rk_cipher_finish

```
TEE_Result rk_cipher_finish(crypto_ctx_t *ctx, uint8_t *out, uint32_t *out_len);
```

Description

Finish the encryption/decryption operation of symmetric encryption/decryption algorithm for multiple.

Parameters

- ctx: crypto context
- out: output data
- out_len: the length of output

14.3.1.12 rk_ae_begin

```
TEE_Result rk_ae_begin(crypto_ctx_t *ctx, uint8_t *key, uint32_t key_len,
                       uint8_t *iv, uint32_t iv_len,
                       uint32_t add_len, uint32_t tag_len,
                       uint32_t payload_len, uint32_t algo, TEE_OperationMode mode);
```

Description

Initialization operations of AES-CCM or AES-GCM algorithms.

Parameters

- ctx: crypto context
- key: the key for calculation
- key_len: the length of key, supports 16, 24, 32
- iv: initialization vector
- iv_len: the length of iv
- add_len: the ADD length of the AES-CCM
- tag_len: the tag length(bit), AES-GCM supports 128, 120, 112, 104, 96, and AES-CCM supports 128, 112, 96, 80, 64, 48, 32
- payload_len: the payload length of the AES-CCM
- algo: algorithm type, support `TEE_ALG_AES_GCM`, `TEE_ALG_AES_CCM`
- mode: encryption or decryption mode

14.3.1.13 rk_ae_update

```
TEE_Result rk_ae_update(crypto_ctx_t *ctx, uint8_t *in, uint8_t *out,
                        uint32_t in_len, uint32_t *out_len,
                        rk_ae_update_type_t is_aad);
```

Description

Encrypts/decrypts the input data for AES-CCM or AES-GCM algorithms.

Parameters

- ctx: crypto context
- in: input data
- in_len: the length of input
- out: output data
- out_len: the length of output
- is_add: identifies whether there is AAD(Additional Authentication Data)

14.3.1.14 rk_ae_finish

```
TEE_Result rk_ae_finish(crypto_ctx_t *ctx, uint8_t *in, uint8_t *out,
                        uint8_t *tag, uint32_t in_len,
                        uint32_t *out_len, uint32_t *tag_len);
```

Description

Complete the encryption/decryption operation for AES-CCM or AES-GCM algorithms.

Parameters

- ctx: crypto context
- in: the last input data
- in_len: the length of the last input data
- out: output data
- out_len: the length of output
- tag: output tag
- tag_len: the length of tag

14.3.1.15 rk_gen_rsa_key

```
TEE_Result rk_gen_rsa_key(rsa_key_t *rsa_key, uint32_t key_len,
                          uint64_t public_exponent);
```

Description

Randomly generate RSA key pairs.

Parameters

- rsa_key: the output RSA key pairs
- key_len: the length of RSA keys (byte), supports 32, 64, 96, 128, 192, 256, 384, 512
- public_exponent: public exponent, supports 3, 65537

14.3.1.16 rk_rsa_crypto

```
TEE_Result rk_rsa_crypto(uint8_t *in, uint8_t *out, uint32_t len,
                         rsa_key_t *key, uint32_t algo, TEE_OperationMode mode);
```

Description

RSA encryption/decryption algorithms. You can also use the `rk_rsa_begin/finish` interface.

Parameters

- in: input data
- len: the length of input
- out: output data
- key: the RSA key
- algo: the padding mode of RSA, supports:

  ```
  TEE_ALG_RSAES_PKCS1_V1_5
  TEE_ALG_RSAES_PKCS1_OAEP_MGF1_SHA1
  TEE_ALG_RSAES_PKCS1_OAEP_MGF1_SHA224
  TEE_ALG_RSAES_PKCS1_OAEP_MGF1_SHA256
  TEE_ALG_RSAES_PKCS1_OAEP_MGF1_SHA384
  TEE_ALG_RSAES_PKCS1_OAEP_MGF1_SHA512
  TEE_ALG_RSA_NOPAD
  ```

- mode: the mode of RSA, supports `TEE_MODE_ENCRYPT` and `TEE_MODE_DECRYPT`

14.3.1.17 rk_rsa_sign

```
TEE_Result rk_rsa_sign(uint8_t *digest, uint8_t *signature, uint32_t digest_len,
                       uint32_t *signature_len, rsa_key_t *key,
                       uint32_t salt_len, uint32_t algo, TEE_OperationMode mode);
```

Description

RSA sign/verify algorithm. You can also use the `rk_rsa_begin/finish` interface.

Parameters

- digest: digest value
- signature: the output value of sign, or the input value to be verified
- digest_len: the length of digest
- signature_len: the length of signature
- key: RSA key
- salt_len: the length of salt, it is optional, if it is 0 then the salt length is equal to the digest length
- algo: algorithm, see `GPD_TEE_Internal_Core_API_Specification, Table 6-4` for details
- mode: the mode of RSA, supports `TEE_MODE_SIGN` and `TEE_MODE_VERIFY`

14.3.1.18 rk_set_sign_mode

```
TEE_Result rk_set_sign_mode(crypto_ctx_t *ctx, unsigned int mode);
```

Description

Set the RSA sign mode, sign data or sign digest.

Parameters

- ctx: crypto context
- mode: `SIGN_DATA` for signing data and `SIGN_DIGEST` for signing digest

14.3.1.19 rk_rsa_begin

```
TEE_Result rk_rsa_begin(crypto_ctx_t *ctx, rsa_key_t *key,
                        uint32_t algo, TEE_OperationMode mode);
```

Description

Initialization of RSA encryption/decryption/sign/verify.

Parameters

- ctx: crypto context
- key: RSA key
- algo: the padding mode of RSA, see `GPD_TEE_Internal_Core_API_Specification, Table 6-4` for details
- mode: algorithm type, support `TEE_MODE_ENCRYPT, TEE_MODE_DECRYPT, TEE_MODE_SIGN, TEE_MODE_VERIFY`

14.3.1.20 rk_rsa_finish

```
TEE_Result rk_rsa_finish(crypto_ctx_t *ctx, uint8_t *in, uint8_t *out,
                         uint32_t in_len, uint32_t *out_len, uint32_t salt_len);
```

Description

RSA algorithm executed after `rk_rsa_begin`.

Parameters

- ctx: crypto context
- in: input data
- in_len: the length of input
- out: output data
- out_len: the length of output
- salt_len: the length of salt, it is optional

14.3.1.21 rk_gen_ec_key

```
TEE_Result rk_gen_ec_key(ec_key_t *ec_key, uint32_t key_len, uint32_t curve);
```

Description

Randomly generate ECC key pairs.

Parameters

- ec_key: the output ECC key pairs
- key_len: the length of key (bit), supports 192, 224, 256, 384, 521
- curve: ECC curve, see `tee_api_defines.h` for details

14.3.1.22 rk_ecdh_genkey

```
TEE_Result rk_ecdh_genkey(uint8_t *private, uint8_t *publicx, uint32_t *publicy,
                          uint32_t algo,  uint32_t curve,
                          uint32_t keysize, uint8_t *out);
```

Description

Perform ECDH to negotiate symmetric key.

Parameters

- private: ECC private key
- publicx: X-coordinate of ECC public key
- publicy: Y-coordinate of ECC public key
- algo: algorithm, supports `TEE_ALG_ECDH_P192`, `TEE_ALG_ECDH_P224`, `TEE_ALG_ECDH_P256`, `TEE_ALG_ECDH_P384`, `TEE_ALG_ECDH_P521`
- curve: ECC curve, supports `TEE_ECC_CURVE_NIST_P192`, `TEE_ECC_CURVE_NIST_P224`, `TEE_ECC_CURVE_NIST_P256`, `TEE_ECC_CURVE_NIST_P384`, `TEE_ECC_CURVE_NIST_P521`
- keysize: the length of key (bit), supports 192, 224, 256, 384, 521
- out: output symmetric key

14.3.1.23 rk_ecdsa_sign

```
TEE_Result rk_ecdsa_sign(uint8_t *digest, uint8_t *signature,
                         uint32_t digest_len, uint32_t *signature_len,
                         ec_key_t *key, uint32_t algo, TEE_OperationMode mode);
```

Description

ECDSA sign/verify algorithm. You can also use the `rk_ecdsa_begin/finish` interface.

Parameters

- digest: input digest
- signature: output signature, or input signature for verified
- digest_len: the length of digest
- signature_len: the length of signature
- key: ECC key

- algo: algorithm, supports `TEE_ALG_ECDSA_P224, TEE_ALG_ECDSA_P256, TEE_ALG_ECDSA_P384, TEE_ALG_ECDSA_P521`
- mode: the mode of ECC, supports `TEE_MODE_SIGN, TEE_MODE_VERIFY`

14.3.1.24 rk_ecdsa_begin

```
TEE_Result rk_ecdsa_begin(crypto_ctx_t *ctx, ec_key_t *key,
                uint32_t algo,TEE_OperationMode mode);
```

Description

Initialization operations of ECDSA.

Parameters

- ctx: crypto context
- key: ECC key
- algo: algorithm, supports `TEE_ALG_ECDSA_P224, TEE_ALG_ECDSA_P256, TEE_ALG_ECDSA_P384, TEE_ALG_ECDSA_P521`
- mode: mode, supports `TEE_MODE_SIGN, TEE_MODE_VERIFY`

14.3.1.25 rk_ecdsa_finish

```
TEE_Result rk_ecdsa_finish(crypto_ctx_t *ctx, uint8_t *in, uint8_t *out,
                uint32_t in_len, uint32_t *out_len);
```

Description

ECDSA signs the input digest, or verifys the input digest and signature.

Parameters

- ctx: crypto context
- in: input digest
- out: output signature, or input signature for verified
- in_len: the length of input
- out_len: the length of output

14.3.1.26 rk_sm2_pke

```
TEE_Result rk_sm2_pke(uint8_t *in, uint32_t in_len, uint8_t *out,
                uint32_t *out_len, ec_key_t *key,
                uint32_t algo, TEE_OperationMode mode);
```

Description

SM2 encryption/decryption. OP-TEE V1 does not support this interface.

Parameters

- in: input data
- in_len: the length of input

- out: output data
- out_len: the length of output
- key: SM2 key
- algo: algorithm, supports `TEE_ALG_SM2_PKE`
- mode: mode, supports `TEE_MODE_ENCRYPT` and `TEE_MODE_DECRYPT`

14.3.1.27 rk_sm2_dsa_sm3

```
TEE_Result rk_sm2_dsa_sm3(uint8_t *digest, uint32_t digest_len,
                          uint8_t *signature, uint32_t *signature_len,
                          ec_key_t *key, uint32_t algo, TEE_OperationMode mode);
```

Description

SM2 sign/verify. OP-TEE V1 does not support this interface.

Parameters

- digest: SM3 digest
- digest_len: the length of SM3 digest, fixed to 32
- signature: output signature, or input signature for verified
- signature_len: the length of signature
- key: SM2 key
- algo: algorithm, supports `TEE_ALG_SM2_DSA_SM3`
- mode: mode, supports `TEE_MODE_SIGN` and `TEE_MODE_VERIFY`

14.3.1.28 rk_sm2_kep_genkey

```
TEE_Result rk_sm2_kep_genkey(rk_sm2_kep_parms *kep_parms, uint8_t *share_key,
                             uint32_t share_key_len, uint8_t *conf_out);
```

Description

ECDH algorithm based on SM2. OP-TEE V1 does not support this interface.

Parameters

- kep_parms: SM2 key infomation, contains the private key of A and the public key of B
- share_key: output symmetric key
- share_key_len: the length of share_key
- conf_out: information for validation

14.3.1.29 rk_mac_crypto

```
TEE_Result rk_mac_crypto(uint8_t *in, uint8_t *out, uint32_t in_len,
                         uint32_t *out_len, uint8_t *key, uint32_t key_len,
                         uint8_t *iv, uint32_t algo);
```

Description

MAC calculation. You can use the `rk_mac_begin/update/finish` interface for multiple calculations.

Parameters

- in: input data
- in_len: the length of input
- out: output data
- out_len: the length of output
- key: MAC key
- key_len: the length of key
- iv: initialization vector
- algo: MAC algorithm type, support the following(OP-TEE V1 dose not support the SM algorithm), `TEE_ALG_HMAC_MD5`, `TEE_ALG_HMAC_SHA1`, `TEE_ALG_HMAC_SHA256`, `TEE_ALG_AES_CMAC`, `TEE_ALG_HMAC_SM3`

14.3.1.30 rk_mac_begin

```
TEE_Result rk_mac_begin(crypto_ctx_t *ctx, uint8_t *key, uint32_t key_len,
                        uint8_t *iv, uint32_t algo);
```

Description

Initialization operation for MAC multiple calculation.

Parameters

- ctx: crypto context
- key: MAC key
- key_len: the length of key
- iv: initialization vector
- algo: MA Calgorithm type, support the following(OP-TEE V1 dose not support the SM algorithm), `TEE_ALG_HMAC_MD5`, `TEE_ALG_HMAC_SHA1`, `TEE_ALG_HMAC_SHA256`, `TEE_ALG_AES_CMAC`, `TEE_ALG_HMAC_SM3`

14.3.1.31 rk_mac_update

```
TEE_Result rk_mac_update(crypto_ctx_t *ctx, uint8_t *in, uint32_t in_len);
```

Description

Input data for MAC multiple calculation.

Parameters

- ctx: crypto context
- in: input data
- in_len: the length of input

14.3.1.32 rk_mac_finish

```
TEE_Result rk_mac_finish(crypto_ctx_t *ctx, uint8_t *in, uint8_t *mac,
                         uint32_t in_len, uint32_t *mac_len, rk_mac_mode_t mode);
```

Description

Input the last part of data and calculate the MAC or Verify the MAC.

Parameters

- ctx: crypto context
- in: the last part of input data
- in_len: the length of in
- mac: `mode=RK_MAC_SIGN` - output calculate MAC value; `mode=RK_MAC_VERIFY` - input MAC value that is verified
- mac_len: the length of mac
- mode: see `mac`

14.3.1.33 rk_hkdf_genkey

```
TEE_Result rk_hkdf_genkey(uint8_t *ikm, uint32_t ikm_len,
                          uint8_t *salt, uint32_t salt_len,
                          uint32_t *info, uint32_t info_len,
                          uint32_t algo, uint32_t okm_len, uint8_t *okm);
```

Description

HKDF key derivation.

Parameters

- ikm: input password
- ikm_len: the length of ikm
- salt: input salt
- salt_len: the length of salt
- info: input info
- info_len: the length of info
- algo: algorithm, supports `TEE_ALG_HKDF_MD5_DERIVE_KEY`, `TEE_ALG_HKDF_SHA1_DERIVE_KEY`, `TEE_ALG_HKDF_SHA224_DERIVE_KEY`, `TEE_ALG_HKDF_SHA256_DERIVE_KEY`, `TEE_ALG_HKDF_SHA384_DERIVE_KEY`, `TEE_ALG_HKDF_SHA512_DERIVE_KEY`
- okm_len: the length of okm
- okm: output key

14.3.1.34 rk_pkcs5_pbkdf2_hmac

```
TEE_Result rk_pkcs5_pbkdf2_hmac(uint8_t *password, uint32_t password_len,
                                uint8_t *salt, uint32_t salt_len,
                                uint32_t iterations, uint32_t algo,
                                uint32_t key_len, uint8_t *out_key);
```

Description

Key derivation by specifying the salt, iteration count and the password.

Parameters

- password: input password
- password_len: the length of password

- salt: input salt
- salt_len: the length of salt
- iterations: input iteration count
- algo: algorithm, supports `TEE_ALG_PBKDF2_HMAC_SHA1_DERIVE_KEY`
- key_len: the length of key
- out_key: output key

14.3.2 HW Crypto API

14.3.2.1 rk_user_ta_cipher

```
TEE_Result rk_user_ta_cipher(rk_cipher_config *config, uint8_t *src, uint32_t len)
```

Description

Use hardware Crypto for encryption and decryption.

Parameters

- config: Algorithm parameters, used to configure algorithm type, algorithm mode, key, etc
- src: Input and output data
- len: Data length

14.3.3 TRNG API

14.3.3.1 rk_get_trng

```
TEE_Result rk_get_trng(uint8_t *buffer, uint32_t size);
```

Description

Get the hardware random number.
Only supported by some platforms, if the interface is not supported, `TEE_ERROR_NOT_SUPPORTED` is returned.

Parameters

- buffer: output random number
- size: the length of buffer

14.3.4 Derive Key API

14.3.4.1 rk_derive_ta_unique_key

```
TEE_Result rk_derive_ta_unique_key(uint8_t *extra, uint16_t extra_size, uint8_t *key, uint16_t key_size)
```

Description

Obtain the key derived from the hardware unique key.

During the production of each chip, a hardware unique key is burned, and the key derived from this hardware unique key is unique.

Parameters

- extra: Input data for derive different keys
- extra_size: Input data length
- key: Derived key
- key_size: Key length

14.3.5 OTP API

14.3.5.1 rk_otp_size

```
TEE_Result rk_otp_size(uint32_t *otp_size);
```

Description

Gets the total size of the Protected OEM Zone in secure OTP.

Parameters

- otp_size: return OTP size

14.3.5.2 rk_otp_read

```
TEE_Result rk_otp_read(uint32_t offset, uint8_t *data, uint32_t len);
```

Description

Read data from Protected OEM Zone in secure OTP.

Parameters

- offset: the position offset of the OTP region to be read
- data: output data
- len: the length of data

14.3.5.3 rk_otp_write

```
TEE_Result rk_otp_write(uint32_t offset, uint8_t *data, uint32_t len);
```

Description

Write data to Protected OEM Zone in secure OTP.

Parameters

- offset: the position offset of the OTP region to be write
- data: input data
- len: the length of data

15. Reference

ARM TrustZone:

https://developer.arm.com/ip-products/security-ip/trustzone

GlobalPlatform:

https://globalplatform.org/

This website can download CA development API reference documents: `TEE Client API Specification`

TA development API reference document: `TEE Internal Core API Specification`

And other architecture reference documents.