Prerequisites

Ubuntu24.04

For Buildroot::

    sudo apt-get install git make gcc g++ bzip2 libncurses-dev

For QEMU::

    sudo apt-get install python3-pip python3-venv python3-sphinx python3-tomli libglib2.0-dev ninja-build libpixman-1-dev libslirp-dev

For ARM-FastModel::

    sudo apt-get install xterm
    Fix the lmutil: sudo ln -s /lib64/ld-linux-x86-64.so.2 /lib64/ld-lsb-x86-64.so.3

Ubuntu22.04

For Buildroot::

    sudo apt-get install git make gcc g++ libncurses-dev

For QEMU::

    sudo apt-get install python3-pip python3-venv python3-sphinx python3-tomli libglib2.0-dev ninja-build libpixman-1-dev libslirp-dev

For ARM-FastModel::

    sudo apt-get install xterm
    Fix the lmutil: sudo ln -s /lib64/ld-linux-x86-64.so.2 /lib64/ld-lsb-x86-64.so.3

Ubuntu20.04

For Buildroot::

    sudo apt-get install git make gcc g++ libncurses-dev

For QEMU:: (ubuntu20 must use the **stable-9.0** or older version)

    sudo apt-get install python3-pip python3-venv python3-sphinx libglib2.0-dev ninja-build libpixman-1-dev libslirp-dev

For ARM-FastModel::

    sudo apt-get install xterm
    Fix the lmutil: sudo ln -s /lib64/ld-linux-x86-64.so.2 /lib64/ld-lsb-x86-64.so.3

Quickest & Easiest Way

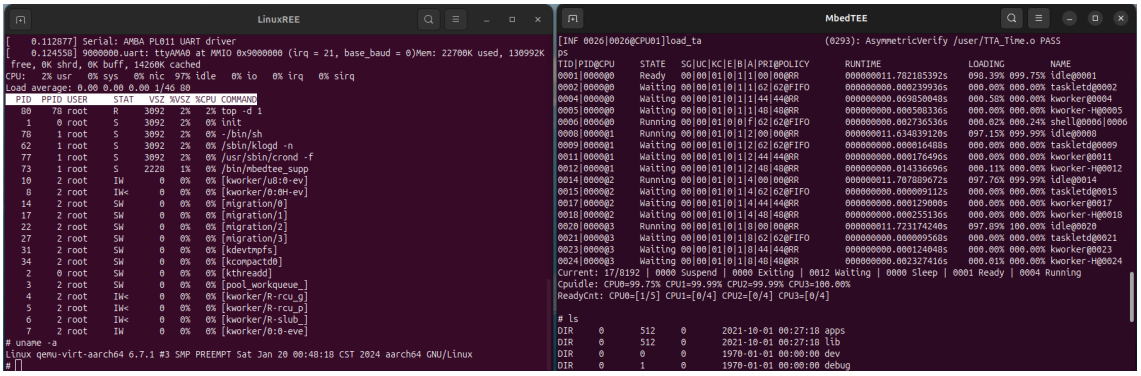
```
git clone https://github.com/mbedtee/mbedtee-build.git
cd mbedtee-build && ./build.sh aarch64 run
```

> **Note**
>
> build.sh is just an example reference for the quick-build/run, **please refer to the following chapters for the detailed build/run commands**.

- **./build.sh aarch64** - build for the QEMU virt aarch64 platform (**build only**)
- **./build.sh aarch64 run** - build and run the QEMU virt aarch64 platform
- **./build.sh aarch32 run** - build and run the QEMU virt aarch32(arm) platform
- **./build.sh riscv64 run** - build and run the QEMU virt riscv64 platform
- **./build.sh riscv32 run** - build and run the QEMU virt riscv32 platform
- **./build.sh mips32 run** - build and run the QEMU malta mips32 platform

Take the QEMU virt AArch64 as example:

- launches 2 gnome-terminal windows, one is for Linux@REE, another one is for the MbedTEE



- Following example command is for **run only**, xterm is also an alternative terminal and can be launched in the similar options.

```
gnome-terminal -e "telnet 127.0.0.1 5555" --tab -t "LinuxREE"& gnome-terminal -e "telnet 127.0.0.1 5556"
--tab -t "MbedTEE"& qemu/build/qemu-system-aarch64 -M virt -M secure=on,gic-version=3,virtualization=on -
cpu cortex-a710 -smp 4 -m 2048 -device
loader,file=buildroot/output/images/mbedtee.bin,addr=0x80000000,force-raw=on -device
loader,file=buildroot/output/images/linux.dtb,addr=0x85F00000,force-raw=on -device
loader,file=buildroot/output/images/Image,addr=0x86000000,force-raw=on -device
loader,addr=0x80000000,cpu-num=0 -device loader,addr=0x80000000,cpu-num=1 -device
loader,addr=0x80000000,cpu-num=2 -device loader,addr=0x80000000,cpu-num=3 -serial
telnet::5555,server,nowait -serial telnet::5556,server,nowait
```

MbedTEE

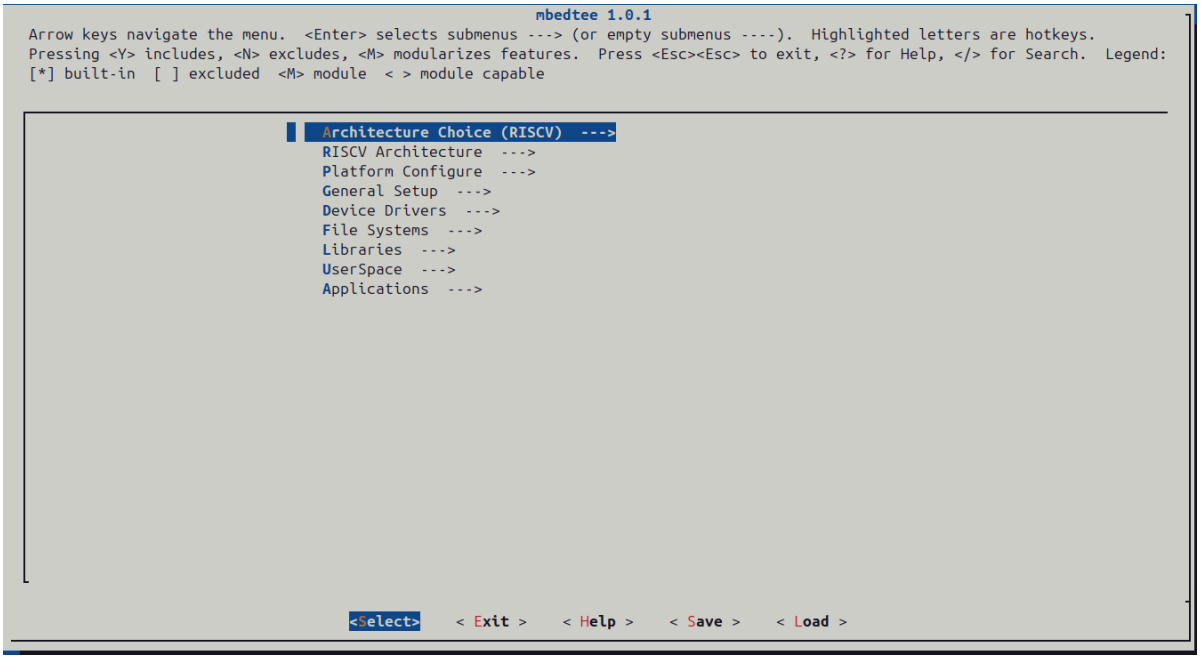
Repositories

https://github.com/mbedtee/mbedtee-build.git	-> entry of building the mbedtee
https://github.com/mbedtee/mbedtee-docs.git	-> documentation of mbedtee
https://github.com/mbedtee/mbedtee-os.git	-> kernel of mbedtee
https://github.com/mbedtee/mbedtee-client-api.git	-> GlobalPlatform style client API @ Linux REE
https://github.com/mbedtee/mbedtee-supp.git	-> REEFS Supplicant System @ Linux UserSpace
https://github.com/mbedtee/mbedtee-common.git	-> Common header files for REE and TEE
https://github.com/mbedtee/mbedtee-crypto.git	-> Cryptographic algorithms for TA encryption and signing
https://github.com/mbedtee/mbedtee-linux-dts.git	-> DTS for Linux REE
https://github.com/mbedtee/mbedtee-globalplatform-client.git	-> GlobalPlatform TestSuite client application @ Linux REE
https://github.com/mbedtee/mbedtee-globalplatform-ta.git	-> GlobalPlatform TestSuite TTAs @ MbedTEE
https://github.com/mbedtee/mbedtee-helloworld-client.git	-> HelloWorld client application @ Linux REE
https://github.com/mbedtee/mbedtee-helloworld-ta.git	-> HelloWorld TA @ MbedTEE

Menuconfig

MbedTEE provides the menuconfig for the feature configuration.

Enter the **buildroot** folder (**mbedtee-build/buildroot**), and issue the command `make mbedtee-os-menuconfig`



Build and Run @ QEMU

Prepare the buildroot

```
git clone https://github.com/mbedtee/mbedtee-build.git
cd mbedtee-build && ./buildroot.sh
```

Configure and Build

Enter the **buildroot** folder, @ **mbedtee-build/buildroot**.

Select one of the following configs, issue the command (e.g. for qemu_virt_aarch64):

```
cd buildroot && make mbedtee_qemu_virt_aarch64_defconfig && make
```

Configs to be selected for QEMU platforms:

```
kapa@ubuntu24:~/mbedtee-build/buildroot$ tree configs/ | grep mbedtee_qemu
├── mbedtee_qemu_malta_mips32r2_defconfig
├── mbedtee_qemu_sifive_u_riscv32_defconfig
├── mbedtee_qemu_sifive_u_riscv64_defconfig
├── mbedtee_qemu_virt_aarch64_defconfig
├── mbedtee_qemu_virt_arm_defconfig
├── mbedtee_qemu_virt_riscv32_defconfig
├── mbedtee_qemu_virt_riscv32_linux_defconfig
├── mbedtee_qemu_virt_riscv64_defconfig
├── mbedtee_qemu_virt_riscv64_linux_defconfig
```

Prepare the QEMU

Enter the **mbedtee-build** folder, clone the QEMU repository to '**mbedtee-build/qemu**'.

```
git clone https://gitlab.com/qemu-project/qemu.git
cd qemu && git checkout stable-9.0
./configure --prefix=$(pwd)/output --enable-slirp --target-list=mips64el-softmmu,mipsel-softmmu,aarch64-softmmu,arm-softmmu,riscv32-softmmu,riscv64-softmmu
make -j4 && make install
```

> ⚠ **Warning**
>
> ubuntu20 must use the **stable-9.0** or older version, ubuntu22/24 can use the 9.1 or newer version.

Run the targets @ QEMU

> ⓘ **Note**
>
> The following configs build/run the targets with MMU/UserSpace enabled, developer can disable MMU/UserSapce to run only the kernel-mode through the menuconfig (or disable the RISCV Supervisor-Mode/MMU/UserSpace, run only the RISCV Machine-Mode).

> **Important**
>
> Switch to the **buildroot** directory (**mbedtee-build/buildroot**) to do the config and make.
>
> “make clean” is required before switching to another target.

AArch64 (REE+TEE)

Config/Make: make mbedtee_qemu_virt_aarch64_defconfig && make

QEMU virt AArch64 targets: -M virt -cpu cortex-a35/cortex-a53/cortex-a55/cortex-a57/cortex-a72/cortex-a76/cortex-a710/neoverse-n1/neoverse-v1/neoverse-n2

```
gnome-terminal -e "telnet 127.0.0.1 5555" --tab -t "LinuxREE"& gnome-terminal -e "telnet 127.0.0.1 5556"
--tab -t "MbedTEE"& ../qemu/build/qemu-system-aarch64 -M virt -M secure=on,gic-
version=3,virtualization=on -cpu cortex-a710 -smp 4 -m 2048 -device
loader,file=output/images/mbedtee.bin,addr=0x80000000,force-raw=on -device
loader,file=output/images/linux.dtb,addr=0x85F00000,force-raw=on -device
loader,file=output/images/Image,addr=0x86000000,force-raw=on -device loader,addr=0x80000000,cpu-num=0 -
device loader,addr=0x80000000,cpu-num=1 -device loader,addr=0x80000000,cpu-num=2 -device
loader,addr=0x80000000,cpu-num=3 -serial telnet::5555,server,nowait -serial telnet::5556,server,nowait

or use the xterm terminal:

xterm -geometry 128x32 -e "telnet localhost 5556" & xterm -geometry 128x32 -e "telnet localhost 5555" &
../qemu/build/qemu-system-aarch64 -M virt -M secure=on,gic-version=3,virtualization=on -cpu cortex-a710 -
smp 4 -m 2048 -device loader,file=output/images/mbedtee.bin,addr=0x80000000,force-raw=on -device
loader,file=output/images/linux.dtb,addr=0x85F00000,force-raw=on  -device
loader,file=output/images/Image,addr=0x86000000,force-raw=on -device loader,addr=0x80000000,cpu-num=0 -
device loader,addr=0x80000000,cpu-num=1 -device loader,addr=0x80000000,cpu-num=2 -device
loader,addr=0x80000000,cpu-num=3 -serial telnet::5555,server,nowait -serial telnet::5556,server,nowait
```

AArch32 (REE+TEE)

There are two kinds of QEMU platforms could run the ARM AArch32, one is "-M virt", another one is "-M vexpress-a15".

QEMU virt AArch32 targets: -M virt -cpu cortex-a15 or cortex-a7

Config/Make: make mbedtee_qemu_virt_arm_defconfig && make

```
gnome-terminal -e "telnet 127.0.0.1 5555" --tab -t "LinuxREE"& gnome-terminal -e "telnet 127.0.0.1 5556"
--tab -t "MbedTEE"& ../qemu/build/qemu-system-arm -M virt -M secure=on -cpu cortex-a15 -smp 4 -m 2048 -
device loader,file=output/images/mbedtee.bin,addr=0x80000000,force-raw=on -device
loader,file=output/images/linux.dtb,addr=0x85F00000,force-raw=on -device
loader,file=output/images/Image,addr=0x86008000,force-raw=on  -device loader,addr=0x80000000,cpu-num=0 -
device loader,addr=0x80000000,cpu-num=1 -device loader,addr=0x80000000,cpu-num=2 -device
loader,addr=0x80000000,cpu-num=3 -serial telnet::5555,server,nowait -serial telnet::5556,server,nowait
```

QEMU vexpress AArch32 target: -M vexpress-a15 -cpu cortex-a15

Config/Make: make mbedtee_vexpress_ca15_defconfig && make

```
xterm -geometry 128x32 -e "telnet 127.0.0.1 5555" & xterm -geometry 128x32 -e "telnet 127.0.0.1 5556" &
xterm -geometry 128x32 -e "telnet 127.0.0.1 5557" & ../qemu/build/qemu-system-arm -M vexpress-a15 -cpu
cortex-a15 -smp 4 -m 2G -device loader,file=output/images/mbedtee.bin,addr=0x80000000,force-raw=on -
device loader,file=output/images/linux.dtb,addr=0x85F00000,force-raw=on -device
loader,file=output/images/Image,addr=0x86008000,force-raw=on -device loader,addr=0x80000000,cpu-num=0 -
device loader,addr=0x80000000,cpu-num=1 -device loader,addr=0x80000000,cpu-num=2 -device
loader,addr=0x80000000,cpu-num=3 -serial telnet::5555,server,nowait -serial telnet::5556,server,nowait -
serial telnet::5557,server,nowait
```

RISCV64 (REE+TEE)

Run with '-smp 8', 4 cores for LinuxREE, 4 cores for MbedTEE.

Config/Make: make mbedtee_qemu_virt_riscv64_linux_defconfig && make

```
../qemu/build/qemu-system-riscv64 -M virt -smp 8 -m 4G -device
loader,file=output/images/fw_jump.bin,addr=0x86000000,force-raw=on -device
loader,file=output/images/Image,addr=0x86200000,force-raw=on -device
loader,file=output/images/mbedtee.bin,addr=0x80000000,force-raw=on -device loader,addr=0x80000000,cpu-
num=0 -device loader,addr=0x80000000,cpu-num=1 -device loader,addr=0x80000000,cpu-num=2 -device
loader,addr=0x80000000,cpu-num=3 -device loader,addr=0x86000000,cpu-num=4 -device
loader,addr=0x86000000,cpu-num=5 -device loader,addr=0x86000000,cpu-num=6 -device
loader,addr=0x86000000,cpu-num=7 -M aclint=on -nographic

or launch a new terminal, QEMU virt AArch64 platform only has 1 UART, so REE/TEE print to the same
terminal:

gnome-terminal -e "telnet 127.0.0.1 6666" --tab -t "LinuxREE + MbedTEE"& ../qemu/build/qemu-system-
riscv64 -M virt -smp 8 -m 4G -device loader,file=output/images/fw_jump.bin,addr=0x86000000,force-raw=on -
device loader,file=output/images/Image,addr=0x86200000,force-raw=on -device
loader,file=output/images/mbedtee.bin,addr=0x80000000,force-raw=on -device loader,addr=0x80000000,cpu-
num=0 -device loader,addr=0x80000000,cpu-num=1 -device loader,addr=0x80000000,cpu-num=2 -device
loader,addr=0x80000000,cpu-num=3 -device loader,addr=0x86000000,cpu-num=4 -device
loader,addr=0x86000000,cpu-num=5 -device loader,addr=0x86000000,cpu-num=6 -device
loader,addr=0x86000000,cpu-num=7 -M aclint=on -nographic -serial telnet::6666,server,nowait
```

RISCV32 (REE+TEE)

Run with '-smp 8', 4 cores for LinuxREE, 4 cores for MbedTEE.

Config/Make: make mbedtee_qemu_virt_riscv32_linux_defconfig && make

```
../qemu/build/qemu-system-riscv32 -M virt -smp 8 -m 2G -device
loader,file=output/images/fw_jump.bin,addr=0x86000000,force-raw=on -device
loader,file=output/images/Image,addr=0x86400000,force-raw=on -device
loader,file=output/images/mbedtee.bin,addr=0x80000000,force-raw=on -device loader,addr=0x80000000,cpu-
num=0 -device loader,addr=0x80000000,cpu-num=1 -device loader,addr=0x80000000,cpu-num=2 -device
loader,addr=0x80000000,cpu-num=3 -M aclint=on -nographic -device loader,addr=0x86000000,cpu-num=4 -device
loader,addr=0x86000000,cpu-num=5 -device loader,addr=0x86000000,cpu-num=6 -device
loader,addr=0x86000000,cpu-num=7

or launch a new terminal, QEMU virt AArch32 platform only has 1 UART, so REE/TEE print to the same
terminal:

gnome-terminal -e "telnet 127.0.0.1 7777" --tab -t "LinuxREE + MbedTEE"& ../qemu/build/qemu-system-
riscv32 -M virt -smp 8 -m 2G -device loader,file=output/images/fw_jump.bin,addr=0x86000000,force-raw=on -
device loader,file=output/images/Image,addr=0x86400000,force-raw=on -device
loader,file=output/images/mbedtee.bin,addr=0x80000000,force-raw=on -device loader,addr=0x80000000,cpu-
num=0 -device loader,addr=0x80000000,cpu-num=1 -device loader,addr=0x80000000,cpu-num=2 -device
loader,addr=0x80000000,cpu-num=3 -M aclint=on -nographic -device loader,addr=0x86000000,cpu-num=4 -device
loader,addr=0x86000000,cpu-num=5 -device loader,addr=0x86000000,cpu-num=6 -device
loader,addr=0x86000000,cpu-num=7 -serial telnet::7777,server,nowait
```

RISCV64 (TEE only)

Config/Make: make mbedtee_qemu_virt_riscv64_defconfig && make

```
../qemu/build/qemu-system-riscv64 -M virt -smp 4 -m 4G -device
loader,file=output/images/mbedtee.bin,addr=0x80000000,force-raw=on -device loader,addr=0x80000000,cpu-
num=0 -device loader,addr=0x80000000,cpu-num=1 -device loader,addr=0x80000000,cpu-num=2 -device
loader,addr=0x80000000,cpu-num=3 -M aclint=on -serial stdio
```

RISCV32 (TEE only)

Config/Make: make mbedtee_qemu_virt_riscv32_defconfig && make

```
../qemu/build/qemu-system-riscv32 -M virt,aclint=on -smp 4 -m 2G -device
loader,file=output/images/mbedtee.bin,addr=0x80000000,force-raw=on -device loader,addr=0x80000000,cpu-
num=0 -device loader,addr=0x80000000,cpu-num=1 -device loader,addr=0x80000000,cpu-num=2 -device
loader,addr=0x80000000,cpu-num=3 -serial stdio
```

SifiveUnleashed RISCV32 (TEE only)

Config/Make: make mbedtee_qemu_sifive_u_riscv32_defconfig && make

```
../qemu/build/qemu-system-riscv32 -M sifive_u -smp 5 -m 2G -device
loader,file=output/images/mbedtee.bin,addr=0x80000000,force-raw=on -device loader,addr=0x80000000,cpu-
num=0 -device loader,addr=0x80000000,cpu-num=1 -device loader,addr=0x80000000,cpu-num=2 -device
loader,addr=0x80000000,cpu-num=3 -device loader,addr=0x80000000,cpu-num=4 -serial stdio
```

SifiveUnleashed RISCV64 (TEE only)

Config/Make: make mbedtee_qemu_sifive_u_riscv64_defconfig && make

```
../qemu/build/qemu-system-riscv64 -M sifive_u -smp 5 -m 4G -device
loader,file=output/images/mbedtee.bin,addr=0x80000000,force-raw=on -device loader,addr=0x80000000,cpu-
num=0 -device loader,addr=0x80000000,cpu-num=1 -device loader,addr=0x80000000,cpu-num=2 -device
loader,addr=0x80000000,cpu-num=3 -device loader,addr=0x80000000,cpu-num=4 -serial stdio
```

Malta MIPS32 (TEE only)

QEMU malta mips32r2 targets: -cpu 24Kf 24Kc 34Kf 74Kf M14Kc P5600

Config/Make: make mbedtee_qemu_malta_mips32r2_defconfig && make

```
../qemu/build/qemu-system-mipsel -M malta -m 1G -cpu 74Kf -kernel output/images/mbedtee.elf -serial stdio
```

Build and Run @ FastModel

Prepare the buildroot

```
git clone https://github.com/mbedtee/mbedtee-build.git
cd mbedtee-build && ./buildroot.sh
```

Configure and Build

Enter the **buildroot** folder, @ **mbedtee-build/buildroot**.

Select one of the following configs, issue the command (e.g. for Cortex-A78x4):

```
cd buildroot && make mbedtee_vexpress_ca78_defconfig && make
```

Configs to be selected for ARM FastModels:

```
kapa@ubuntu24:~/mbedtee-build/buildroot$ tree configs/ | grep mbedtee_vexpress
├── mbedtee_vexpress_ca15_defconfig
├── mbedtee_vexpress_ca17x4_ca7x4_defconfig
├── mbedtee_vexpress_ca510x4_ca710x4_defconfig
├── mbedtee_vexpress_ca53_defconfig
├── mbedtee_vexpress_ca5_defconfig
├── mbedtee_vexpress_ca65_defconfig
├── mbedtee_vexpress_ca73x4_ca53x4_defconfig
├── mbedtee_vexpress_ca78_defconfig
```

Prepare the FastModel

1. Before setup the LicenseManager and FastModel SystemCanvas, please get a Fast Model Library license from support@arm.com, then generate your **license.dat** from below website.

   https://developer.arm.com/support/licensing/generate

2. Download the License Management tool - BX002-PT-00007-r11p17-02rel0.tar.gz.

   https://developer.arm.com/Tools%20and%20Software/License%20Management#Downloads

3. Download "Fast Models 11.23 for Linux x86" from the below ARM website:

   https://developer.arm.com/downloads/view/FM000A?sortBy=availableBy&revision=r11p23-09rel0

4. Setup and stop/start the license manager (assume your license.dat is in **~/** folder):

   ```
   tar xvf BX002-PT-00007-r11p17-02rel0.tar.gz
   ./BX002-PT-00007-r11p17-02rel0/lmutil lmdown -c ~/license.dat
   ./BX002-PT-00007-r11p17-02rel0/lmgrd -c ~/license.dat -l
   ```

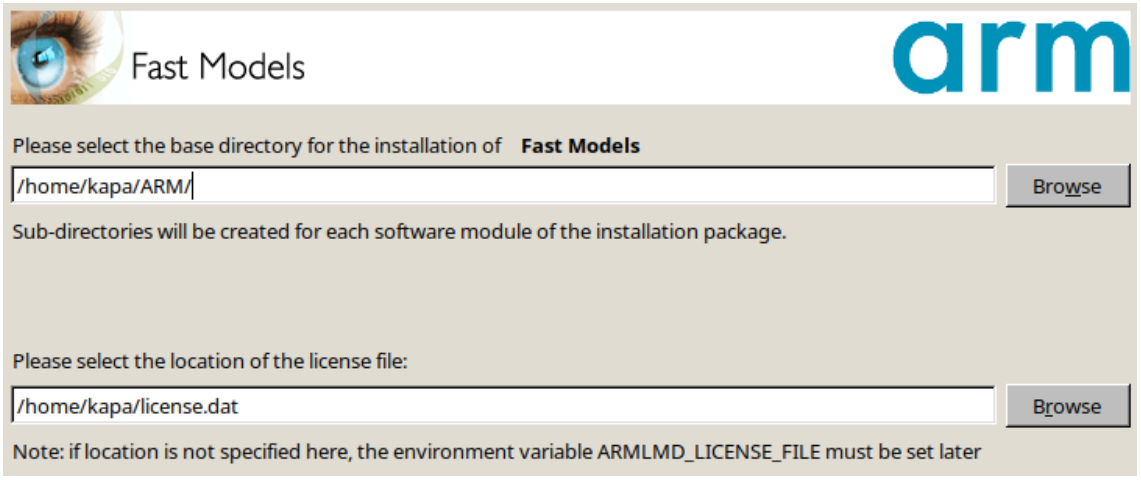
   Make sure the Ubuntu MAC and the name of the account currently logged on are consistent with the MAC/Name used for generating license.dat.

   When success, you will see the log: **(armlmd) DPLT: waiting for logger to connect**

5. Setup the "Fast Models 11.23 for Linux x86"

   ```
   tar xvf FastModels_11-23-009_Linux64.tgz
   ./FastModels_11-23-009_Linux64/setup.bin
   ```

   Specify the installation directory and the location of the license.dat, then next util finish.

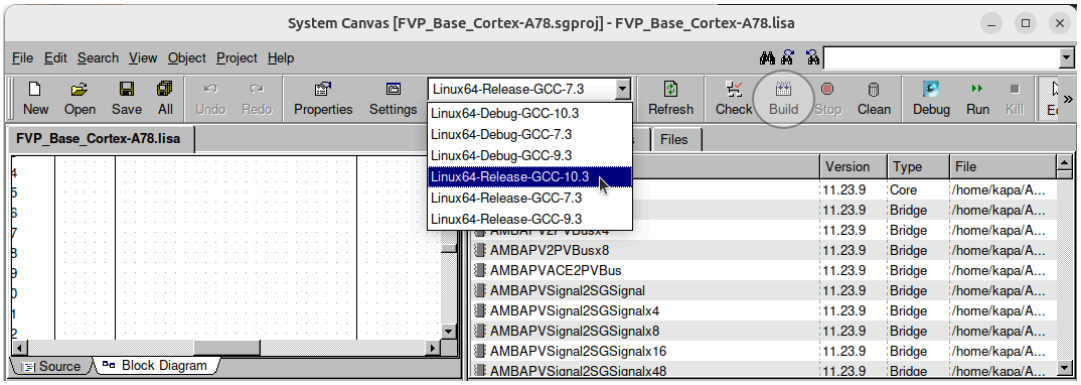


6. Run the FastModel SystemCanvas (Setting the environment path and run the **sgcanvas**)

```
. /home/kapa/ARM/FastModelsTools_11.23/source_all.sh
sgcanvas
```

7. Build the FastModel targets (e.g. for AArch64 Cortex-A78)
   - Load project: Click the System Canvas "**File**" -> "**Load Project**" -> Select the **ARM/FastModelsPortfolio_11.23/examples/LISA/FVP_Base/Build_Cortex-A78/FVP_Base_Cortex-A78.sgproj**
   - Select Active Project Configuration -> **Linux-Release-GCC-10.3**
   - Click the **Build**, waiting for 3 ~ 5 minutes for building the target model libraries, check the Log window for success or failure information,

     "Model Build process completed successfully." means for a successful building.

   - Other targets can be built in the similar way.

Run the targets @ FastModel

> **Important**
>
> Switch to the **buildroot** directory (**mbedtee-build/buildroot**) to do the config and make.
>
> “make clean” is required before switching to another target.

AArch64 (CA78 Series)

- Config/Make: make mbedtee_vexpress_ca78_defconfig && make

  Support targets:

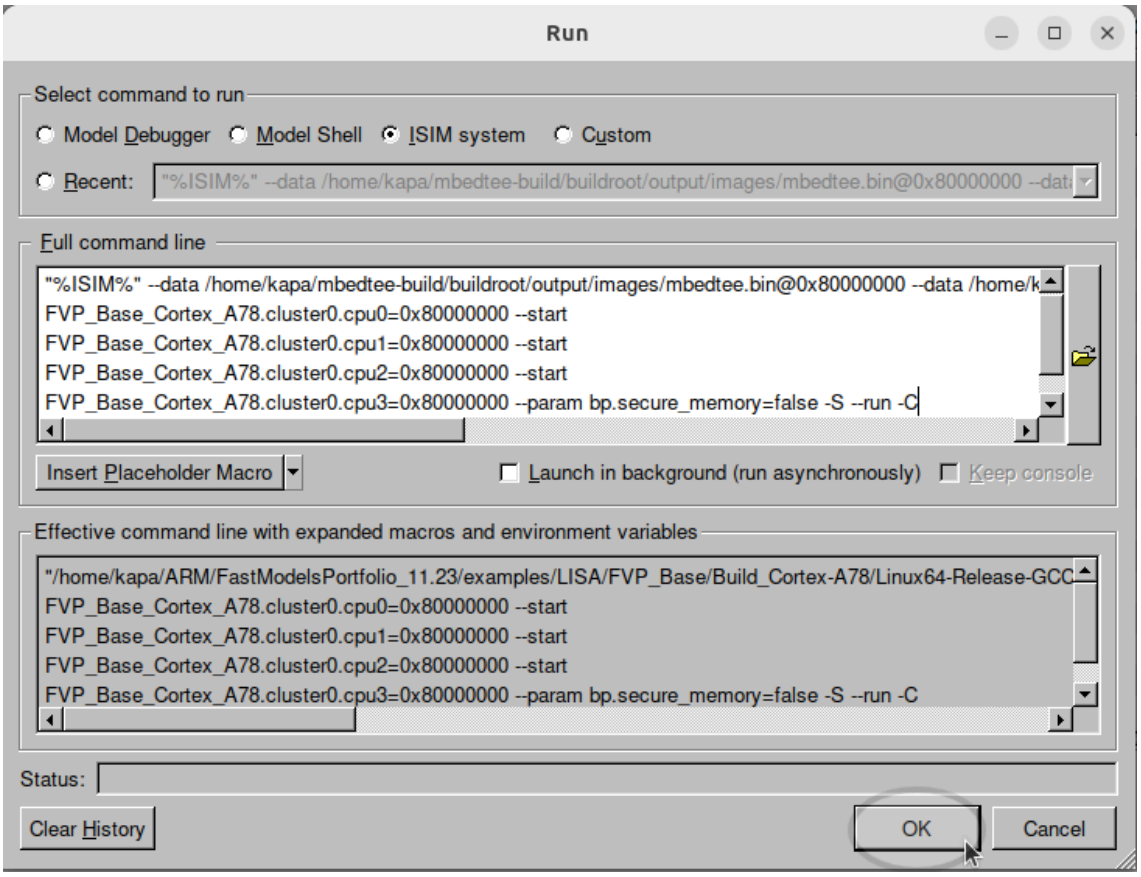
```
FVP_Base_Cortex_A55x4, FVP_Base_Cortex_A75x4, FVP_Base_Cortex_A76x4, FVP_Base_Cortex_A77x4
FVP_Base_Cortex_A78x4, FVP_Base_Cortex_X1x4, FVP_Base_Cortex_A510x4, FVP_Base_Cortex_A710x4
FVP_Base_Cortex_X2x4, FVP_Base_Neoverse_N1x4, FVP_Base_Neoverse_V1x4, FVP_Base_Neoverse_N2x4
```

- System Canvas - Load project: Click the "**File**" -> "**Load Project**" -> Select the **ARM/FastModelsPortfolio_11.23/examples/LISA/FVP_Base/Build_Cortex-A78/FVP_Base_Cortex-A78.sgproj**

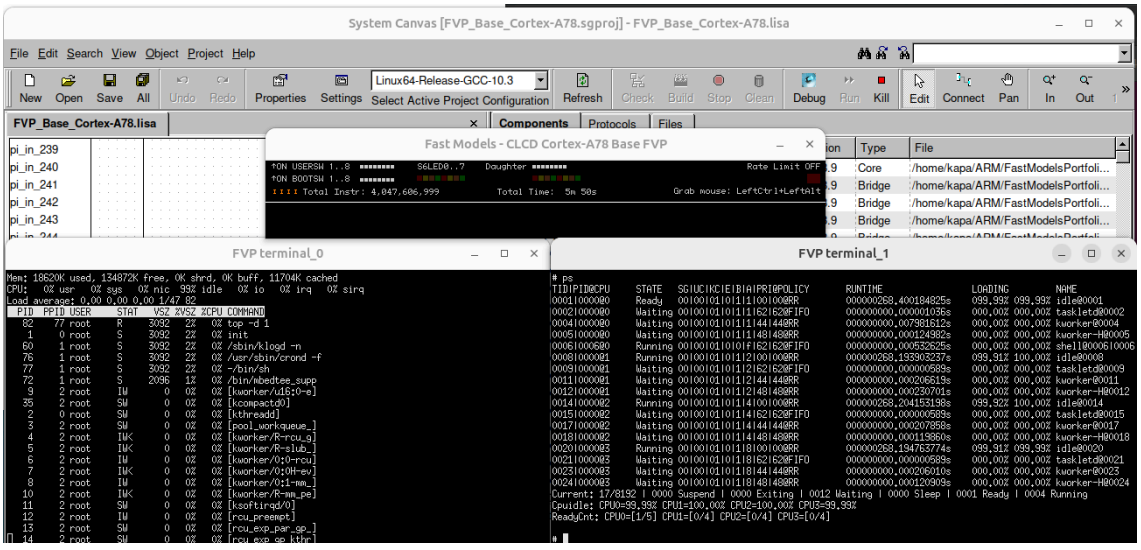
- System Canvas - Select Active Project Configuration -> **Linux-Release-GCC-10.3** and then click the **Build** button
- System Canvas - Click the **Run** button -> Select the **ISIM system** -> Input below command to run the target -> Click **OK**

```
"%ISIM%" --data /home/kapa/mbedtee-build/buildroot/output/images/mbedtee.bin@0x80000000 --data
/home/kapa/mbedtee-build/buildroot/output/images/linux.dtb@0x85f00000 --data /home/kapa/mbedtee-
build/buildroot/output/images/Image@0x86000000 --start FVP_Base_Cortex_A78.cluster0.cpu0=0x80000000
--start FVP_Base_Cortex_A78.cluster0.cpu1=0x80000000 --start
FVP_Base_Cortex_A78.cluster0.cpu2=0x80000000 --start FVP_Base_Cortex_A78.cluster0.cpu3=0x80000000 --
param bp.secure_memory=false -S --run -C pctl.startup=0.0.*.0 -C bp.vis.rate_limit-enable=false
```

- Command window of Run:



- xterm will be launched for LinuxREE (FVP terminal_0) and MbedTEE (FVP terminal_1) :



AArch64 (CA53 Series)

- Config/Make: make mbedtee_vexpress_ca53_defconfig && make

  Support targets:

```
FVP_Base_Cortex_A53x4, FVP_Base_Cortex_A35x4, FVP_Base_Cortex_A57x4, FVP_Base_Cortex_A72x4,
FVP_Base_Cortex_A73x4
```

- System Canvas - Load project: Click the "**File**" -> "**Load Project**" -> Select the

  ARM/FastModelsPortfolio_11.23/examples/LISA/FVP_Base/Build_Cortex-A53x4/FVP_Base_Cortex-A53x4.sgproj
- System Canvas - Select Active Project Configuration -> **Linux-Release-GCC-10.3** and then click the **Build** button
- System Canvas - Click the **Run** button -> Select the **ISIM system** -> Input below command to run the target -> Click **OK**

```
"%ISIM%" --data /home/kapa/mbedtee-build/buildroot/output/images/mbedtee.bin@0x80000000 --data
/home/kapa/mbedtee-build/buildroot/output/images/linux.dtb@0x85f00000 --data /home/kapa/mbedtee-
build/buildroot/output/images/Image@0x86000000 --start
FVP_Base_Cortex_A53x4.cluster0.cpu0=0x80000000 --start
FVP_Base_Cortex_A53x4.cluster0.cpu1=0x80000000 --start
FVP_Base_Cortex_A53x4.cluster0.cpu2=0x80000000 --start
FVP_Base_Cortex_A53x4.cluster0.cpu3=0x80000000 --param bp.secure_memory=false -S --run -C
pctl.startup=0.0.0.* -C bp.vis.rate_limit-enable=false
```

AArch64 (big.LITTLE)

- Config/Make: make mbedtee_vexpress_ca73x4_ca53x4_defconfig && make

  Support targets:

```
FVP_Base_Cortex_A73x4_A53x4, FVP_Base_Cortex_A72x4_A53x4, FVP_Base_Cortex_A57x4_A53x4
FVP_Base_Cortex_A72x4_A35x4, FVP_Base_Cortex_A57x4_A35x4
```

- System Canvas - Load project: Click the "**File**" -> "**Load Project**" -> Select the

  ARM/FastModelsPortfolio_11.23/examples/LISA/FVP_Base/Build_Cortex-A73x4-A53x4/FVP_Base_Cortex-A73x4-A53x4.sgproj
- System Canvas - Select Active Project Configuration -> **Linux-Release-GCC-10.3** and then click the **Build** button
- System Canvas - Click the **Run** button -> Select the **ISIM system** -> Input below command to run the target -> Click **OK**

```
"%ISIM%" --data /home/kapa/mbedtee-build/buildroot/output/images/mbedtee.bin@0x80000000 --data
/home/kapa/mbedtee-build/buildroot/output/images/linux.dtb@0x85f00000 --data /home/kapa/mbedtee-
build/buildroot/output/images/Image@0x86000000 --start
FVP_Base_Cortex_A73x4_A53x4.cluster0.cpu0=0x80000000 --start
FVP_Base_Cortex_A73x4_A53x4.cluster0.cpu1=0x80000000 --start
FVP_Base_Cortex_A73x4_A53x4.cluster0.cpu2=0x80000000 --start
FVP_Base_Cortex_A73x4_A53x4.cluster0.cpu3=0x80000000 --start
FVP_Base_Cortex_A73x4_A53x4.cluster1.cpu0=0x80000000 --start
FVP_Base_Cortex_A73x4_A53x4.cluster1.cpu1=0x80000000 --start
FVP_Base_Cortex_A73x4_A53x4.cluster1.cpu2=0x80000000 --start
FVP_Base_Cortex_A73x4_A53x4.cluster1.cpu3=0x80000000 --param bp.secure_memory=false -S --run -C
pctl.startup=0.0.*.* -C bp.vis.rate_limit-enable=false
```

AArch64 (big.LITTLE)

- Config/Make: make mbedtee_vexpress_ca510x4_ca710x4_defconfig && make

  Support targets:

```
FVP_Base_Cortex_A510x4_A710x4, FVP_Base_Cortex_A55x4_A75x4, FVP_Base_Cortex_A55x4_A78x4
```

- System Canvas - Load project: Click the "**File**" -> "**Load Project**" -> Select the

  ARM/FastModelsPortfolio_11.23/examples/LISA/FVP_Base/Build_Cortex-A510x4+Cortex-A710x4/FVP_Base_Cortex-A510x4+Cortex-A710x4.sgproj
- System Canvas - Select Active Project Configuration -> **Linux-Release-GCC-10.3** and then click the **Build** button
- System Canvas - Click the **Run** button -> Select the **ISIM system** -> Input below command to run the target -> Click **OK**

```
"%ISIM%" --data /home/kapa/mbedtee-build/buildroot/output/images/mbedtee.bin@0x80000000 --data
/home/kapa/mbedtee-build/buildroot/output/images/linux.dtb@0x85f00000 --data /home/kapa/mbedtee-
build/buildroot/output/images/Image@0x86000000 -C pctl.startup=0.0.*.* --start
FVP_Base_Cortex_A510x4_Cortex_A710x4.cluster0.subcluster0.cpu0=0x80000000 --start
FVP_Base_Cortex_A510x4_Cortex_A710x4.cluster0.subcluster0.cpu1=0x80000000 --start
FVP_Base_Cortex_A510x4_Cortex_A710x4.cluster0.subcluster0.cpu2=0x80000000 --start
FVP_Base_Cortex_A510x4_Cortex_A710x4.cluster0.subcluster0.cpu3=0x80000000 --start
FVP_Base_Cortex_A510x4_Cortex_A710x4.cluster0.subcluster1.cpu0=0x80000000 --start
FVP_Base_Cortex_A510x4_Cortex_A710x4.cluster0.subcluster1.cpu1=0x80000000 --start
FVP_Base_Cortex_A510x4_Cortex_A710x4.cluster0.subcluster1.cpu2=0x80000000 --start
FVP_Base_Cortex_A510x4_Cortex_A710x4.cluster0.subcluster1.cpu3=0x80000000 --param
bp.secure_memory=false -S --run -C bp.vis.rate_limit-enable=false
```

AArch64 (SMT)

- Config/Make: make mbedtee_vexpress_ca65_defconfig && make

  Support targets: (**Simultaneous Multithreading**: Each core has 2 threads, configured to 8 cores, total 8x2=16 threads)

  ```
  FVP_Base_Cortex_A65, FVP_Base_Cortex_A65AE, FVP_Base_Neoverse_E1
  ```

- System Canvas - Load project: Click the "**File**" -> "**Load Project**" -> Select the **ARM/FastModelsPortfolio_11.23/examples/LISA/FVP_Base/Build_Cortex-A65/FVP_Base_Cortex-A65.sgproj**
- System Canvas - Select Active Project Configuration -> **Linux-Release-GCC-10.3** and then click the **Build** button
- System Canvas - Click the **Run** button -> Select the **ISIM system** -> Input below command to run the target -> Click **OK**

  ```
  "%ISIM%" --data /home/kapa/mbedtee-build/buildroot/output/images/mbedtee.bin@0x80200000 --data
  /home/kapa/mbedtee-build/buildroot/output/images/linux.dtb@0x85f00000 --data /home/kapa/mbedtee-
  build/buildroot/output/images/Image@0x86000000 --start
  FVP_Base_Cortex_A65.cluster0.cpu0.thread0=0x80200000 --start
  FVP_Base_Cortex_A65.cluster0.cpu0.thread1=0x80200000 --start
  FVP_Base_Cortex_A65.cluster0.cpu1.thread0=0x80200000 --start
  FVP_Base_Cortex_A65.cluster0.cpu1.thread1=0x80200000 --start
  FVP_Base_Cortex_A65.cluster0.cpu2.thread0=0x80200000 --start
  FVP_Base_Cortex_A65.cluster0.cpu2.thread1=0x80200000 --start
  FVP_Base_Cortex_A65.cluster0.cpu3.thread0=0x80200000 --start
  FVP_Base_Cortex_A65.cluster0.cpu3.thread1=0x80200000 --start
  FVP_Base_Cortex_A65.cluster0.cpu4.thread0=0x80200000 --start
  FVP_Base_Cortex_A65.cluster0.cpu4.thread1=0x80200000 --start
  FVP_Base_Cortex_A65.cluster0.cpu5.thread0=0x80200000 --start
  FVP_Base_Cortex_A65.cluster0.cpu5.thread1=0x80200000 --start
  FVP_Base_Cortex_A65.cluster0.cpu6.thread0=0x80200000 --start
  FVP_Base_Cortex_A65.cluster0.cpu6.thread1=0x80200000 --start
  FVP_Base_Cortex_A65.cluster0.cpu7.thread0=0x80200000 --start
  FVP_Base_Cortex_A65.cluster0.cpu7.thread1=0x80200000 --param bp.secure_memory=false -S --run -C
  pctl.startup=0.0.*.* -C bp.vis.rate_limit-enable=false
  ```

AArch32 (CA15 Series)

- Config/Make: make mbedtee_vexpress_ca15_defconfig && make

  Support targets:

  ```
  FVP_VE_Cortex_A15x4, FVP_VE_Cortex_A7x4, FVP_VE_Cortex_A17x4
  ```

- System Canvas - Load project: Click the "**File**" -> "**Load Project**" -> Select the **ARM/FastModelsPortfolio_11.23/examples/LISA/FVP_VE/Build_Cortex-A15x4/FVP_VE_Cortex-A15x4.sgproj**
- System Canvas - Select Active Project Configuration -> **Linux-Release-GCC-10.3** and then click the **Build** button
- System Canvas - Click the **Run** button -> Select the **ISIM system** -> Input below command to run the target -> Click **OK**

```
"%ISIM%" --data /home/kapa/mbedtee-build/buildroot/output/images/mbedtee.bin@0x80100000 --data
/home/kapa/mbedtee-build/buildroot/output/images/linux.dtb@0x85F00000 --data /home/kapa/mbedtee-
build/buildroot/output/images/Image@0x86008000 --start FVP_VE_Cortex_A15x4.cluster.cpu0=0x80100000 -
-start FVP_VE_Cortex_A15x4.cluster.cpu1=0x80100000 --start
FVP_VE_Cortex_A15x4.cluster.cpu2=0x80100000 --start FVP_VE_Cortex_A15x4.cluster.cpu3=0x80100000 --
param motherboard.vis.rate_limit-enable=false
```

AArch32 (CA9 Series)

- Config/Make: make mbedtee_vexpress_ca5_defconfig && make

  Support targets:

  ```
  FVP_VE_Cortex_A5x4, FVP_VE_Cortex_A9x4
  ```

- System Canvas - Load project: Click the "**File**" -> "**Load Project**" -> Select the

  ARM/FastModelsPortfolio_11.23/examples/LISA/FVP_VE/Build_Cortex-A9x4/FVP_VE_Cortex-A9x4.sgproj
- System Canvas - Select Active Project Configuration -> **Linux-Release-GCC-10.3** and then click the **Build** button
- System Canvas - Click the **Run** button -> Select the **ISIM system** -> Input below command to run the target -> Click **OK**

  ```
  "%ISIM%" --data /home/kapa/mbedtee-build/buildroot/output/images/mbedtee.bin@0x80000000 --data
  /home/kapa/mbedtee-build/buildroot/output/images/linux.dtb@0x85F00000 --data /home/kapa/mbedtee-
  build/buildroot/output/images/Image@0x86008000 --start FVP_VE_Cortex_A9x4.cluster.cpu0=0x80000000 --
  start FVP_VE_Cortex_A9x4.cluster.cpu1=0x80000000 --start FVP_VE_Cortex_A9x4.cluster.cpu2=0x80000000
  --start FVP_VE_Cortex_A9x4.cluster.cpu3=0x80000000 --param motherboard.vis.rate_limit-enable=false
  ```

AArch32 (big.LITTLE)

- Config/Make: make mbedtee_vexpress_ca17x4_ca7x4_defconfig && make

  Support targets:

  ```
  FVP_VE_Cortex_A17x4_A7x4, FVP_VE_Cortex_A15x4_A7x4
  ```

- System Canvas - Load project: Click the "**File**" -> "**Load Project**" -> Select the

  ARM/FastModelsPortfolio_11.23/examples/LISA/FVP_VE/Build_Cortex-A17x4-A7x4/FVP_VE_Cortex-A17x4-A7x4.sgproj
- System Canvas - Select Active Project Configuration -> **Linux-Release-GCC-10.3** and then click the **Build** button
- System Canvas - Click the **Run** button -> Select the **ISIM system** -> Input below command to run the target -> Click **OK**

  ```
  "%ISIM%" --data /home/kapa/mbedtee-build/buildroot/output/images/mbedtee.bin@0x80000000 --data
  /home/kapa/mbedtee-build/buildroot/output/images/linux.dtb@0x85f00000 --data /home/kapa/mbedtee-
  build/buildroot/output/images/Image@0x86008000 -C
  FVP_VE_Cortex_A17x4_A7x4.coretile.dualclustersystemconfigurationblock.CFG_ACTIVECLUSTER=3 --param
  motherboard.vis.rate_limit-enable=false --start
  FVP_VE_Cortex_A17x4_A7x4.coretile.cluster0.cpu0=0x80000000 --start
  FVP_VE_Cortex_A17x4_A7x4.coretile.cluster0.cpu1=0x80000000 --start
  FVP_VE_Cortex_A17x4_A7x4.coretile.cluster0.cpu2=0x80000000 --start
  FVP_VE_Cortex_A17x4_A7x4.coretile.cluster0.cpu3=0x80000000 --start
  FVP_VE_Cortex_A17x4_A7x4.coretile.cluster1.cpu0=0x80000000 --start
  FVP_VE_Cortex_A17x4_A7x4.coretile.cluster1.cpu1=0x80000000 --start
  FVP_VE_Cortex_A17x4_A7x4.coretile.cluster1.cpu2=0x80000000 --start
  FVP_VE_Cortex_A17x4_A7x4.coretile.cluster1.cpu3=0x80000000 -S --run
  ```

GlobalPlatform

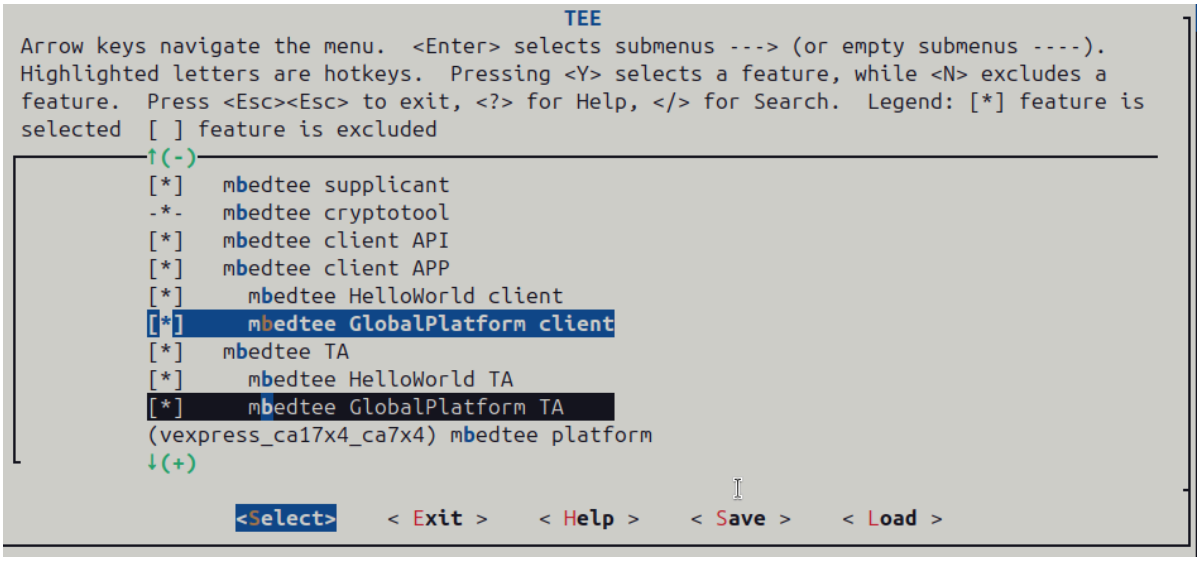
MbedTEE GlobalPlatform TestSuite is porting from **TEE_Initial_Configuration-Test_Suite_v2_0_0_2-2017_06_09.7z**, and it's put in two git repositories, one is for REE client, another one is for TEE TTAs:

```
https://github.com/mbedtee/mbedtee-globalplatform-client.git
https://github.com/mbedtee/mbedtee-globalplatform-ta.git
```

If you are a member of GlobalPlatform or you have purchased the TEE_Initial_Configuration-Test_Suite, you can mail to author to request the access right of these two git repositories.

The GlobalPlatform TestSuite can be enabled through buildroot menuconfig, buildroot clones them from above repositories and then build them:

make menuconfig -> Enter the "**TEE**" menu -> Select the "**mbedtee GlobalPlatform client**" and "**mbedtee GlobalPlatform TA**" -> **make all**

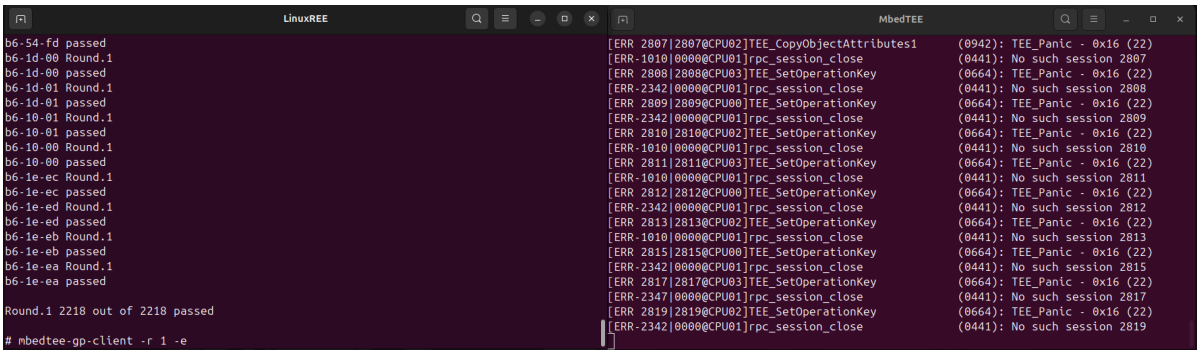


After successfully made the GlobalPlatform TestSuite, you can run the test via **mbedtee-gp-client** application at LinuxREE terminal:

```
# mbedtee-gp-client -h
VERSION: 1.0
mbedtee-gp-client [-h|-s case|-r n] -e

h: help.
e: errexit on any test case failure
r: repeat times of test rounds, default -1.
s: specified the test case
   if no speficied case, all[2218] cases will be tested

   d3-26-21  d3-fe-f9  d3-de-ad  d3-28-c9  d3-87-46  29-ff-45  29-85-65  29-a6-7a
   29-7a-e2  29-8e-75  29-ab-17  29-13-74  29-4c-5c  29-0c-d9  29-d1-8f  29-60-85
   ......
```



Adding TA

In general, you can add your own trusted applications by referencing the **mbedtee-helloworld-ta** and **mbedtee-helloworld-client**.

- Top level Makefile @ buildroot - mbedtee-helloworld-ta.mk:
  - specifies the cross-toolchain and architectured compile options
  - encrypts and signs the compiled TA ELF object

```
kapa@ubuntu24:~/mbedtee-build/buildroot$ tree tee/mbedtee/mbedtee-ta/mbedtee-helloworld-ta/
tee/mbedtee/mbedtee-ta/mbedtee-helloworld-ta/
├── Config.in
└── mbedtee-helloworld-ta.mk
```

- Lower level source code @ TA source tree:
  - provide the TA source and configuration
  - compile the TA ELF object
  - the whole certificate and ELF image are encrypted with AES-128-CBC-CTS (CTS = CBC-CS3) with multi-level keys
  - the certificate and image are signed with RSA-2048 SHA256 [PKCS#1_V1.5], the signature is located at the end of file

```
kapa@ubuntu24:~/mbedtee-build/buildroot$ tree dl/mbedtee-helloworld-ta/git
dl/mbedtee-helloworld-ta/git
├── LICENSE
├── Makefile
├── mbedtee-helloworld-ta.c
├── mbedtee-helloworld-ta.config
└── README.md

└── signed
    ├── mbedtee-helloworld-ta.certi
    └── mbedtee-helloworld-ta.o
```

- TA configuration @ mbedtee-helloworld-ta.config:
  - provide the basic TA information, e.g. Name/UUID/ELF-Path etc.

```
name = "mbedtee-helloworld-ta";
uuid = "6d809454-ccb2-4ed9-b7cf-92447354b367";
path = "/user/mbedtee-helloworld-ta.o";
version = "1.0.0";
stack_size = "8192";
heap_size = "1048576";
single_instance = "1";
multi_session = "1";
dev_access = "/dev/uart0, /dev/uart1, /dev/urandom, /dev/globalplatform";
description = "Hello World";
```

> **Important**
>
> The MbedTEE ELF loader needs the **.symtab and .strtab** sections to locate the GlobalPlatform specified TA entries, such as (*TA_CreateEntryPoint/TA_DestroyEntryPoint/TA_OpenSessionEntryPoint/TA_CloseSessionEntryPoint/TA_InvokeCommandEntry Point*), so please DO NOT strip these two sections in the complied TA ELF object, usually you can refer to the method in Makefile@mbedtee-helloworld-ta:
>
> **${STRIP} -d -R .comment ${APP}** ## this strip option removes the unnecessary sections and keeps the **.symtab and .strtab** sections.

Debugging

Backtrace

- Enable the user space and kernel space backtrace through `make mbedtee-os-menuconfig`
- Example of a fault from user space:

```
[INF 0081|0058@CPU02]backtrace                    (0138):
#1        <00000049f8f23f38>                      (shm_open + 0xbc)
#2        <00000049f8d40890>                      (shmfs_mmap1.isra.0 + 0x84)
#3        <00000049f8d4250c>                      (fs_test_entry + 0x68)
#4        <00000049f8d42a9c>                      (t2_routine + 0xc4)
#5        <00000049f8f24f2c>                      (pthread_entry + 0x2c)
```

- Example of a fault from kernel space:

```
auth_ta@0053|0027 backtrace - kernel
#0        <ffffffc000024520>                      (fat_rename + 0x150)
#1        <ffffffc000021744>                      (sys_rename + 0x7c)
#2        <ffffffc000006964>                      (do_syscall_rename + 0x50)
#3        <ffffffc00004b764>                      (syscall_handler + 0x94)
#4        <ffffffc00003441c>                      (synchronous_el0 + 0x1c)
[INF 0053|0027@CPU02]backtrace - user             (0138):
#1        <00000044150b18dc>                      (__syscall + 0x8)
#2        <00000044150afb5c>                      (_rename_r + 0x1c)
#3        <0000004414ecbae8>                      (fstest + 0x6c8)
#4        <0000004414ecf508>                      (fs_test_entry + 0x64)
#5        <0000004414ecfa9c>                      (t2_routine + 0xc4)
#6        <00000044150b1f24>                      (pthread_entry + 0x2c)
```

Oops

Kernel exception handler is able to provide the exception information and dump the registers:

```
[ERR-0053|0027@CPU02]__oops                       (0169): address: 0xffffffffffffffff
[ERR-0053|0027@CPU02]__oops                       (0170): sp 0xffffffbfc024f930
[ERR-0053|0027@CPU02]__oops                       (0171): spsr 0x60000304
[ERR-0053|0027@CPU02]__oops                       (0172): exception class: 0x25
[ERR-0053|0027@CPU02]__oops                       (0173): exception iss: 0x45
[ERR-0053|0027@CPU02]__oops                       (0174): encoding: DABT (current EL)
[ERR-0053|0027@CPU02]__oops                       (0178): oops@auth_ta@0053|0027 asid 3
usp(0x2000@0x4414e8f000)
[ERR-0053|0027@CPU02]__oops                       (0187): pc 0xffffffc000024520 (fat_rename + 150)
[ERR-0053|0027@CPU02]__oops                       (0190): lr 0xffffffc00002451c (fat_rename + 14c)

x[00~03] ffffffffffffffff 0000000000000000 0000000000000001 0000000000000000
x[04~07] ffffffbfc024fbc8 0000000000000004 4f481f40533d2c3b 7f7f7f7f7f7f7f7f
x[08~11] 0101010101010101 000000000000002f 000000000000002f 0000000000000000
x[12~15] 00030000401b7000 0000004414e90a88 0000000000000300 ffffffbfc024e000
x[16~19] 0000004415164620 00000044150b18d4 0000000000000000 00000000ffffffff0
x[20~23] ffffffbfc0094a08 ffffffc000276215 ffffffbfc0094970 ffffffc0000243d0
x[24~27] ffffffc0000523ba 0000004414e90bc8 0000004414e90dc8 0000000000001092
x[28~29] 000000000000000a ffffffbfc024fbd0
```

Shell

MbedTEE provide a simple shell which can provide some basic commands to query the system information:

- ps/ls/mem/rm/kill/irq/date/mount etc..

```
# ps
TID|PID@CPU     STATE   SG|UC|KC|E|B|A|PRI@POLICY       RUNTIME                LOADING         NAME
0001|0000@0     Ready   00|00|01|0|1|1|00|00@RR         000000309.215397304s    099.89% 099.96% idle@0001
0002|0000@0     Waiting 00|00|01|0|1|1|62|62@FIFO       000000000.000623288s    000.00% 000.00% taskletd@0002
0004|0000@0     Waiting 00|00|01|0|1|1|44|44@RR         000000000.096608240s    000.03% 000.00% kworker@0004
0005|0000@0     Waiting 00|00|01|0|1|1|48|48@RR         000000000.013861808s    000.00% 000.00% kworker-H@0005
0006|0006@0     Running 00|00|01|0|0|f|62|62@FIFO       000000000.010114440s    000.00% 000.03% shell@0006|0006
0008|0000@1     Running 00|00|01|0|1|2|00|00@RR         000000309.127846776s    099.87% 099.98% idle@0008
0009|0000@1     Waiting 00|00|01|0|1|2|62|62@FIFO       000000000.000018064s    000.00% 000.00% taskletd@0009
0011|0000@1     Waiting 00|00|01|0|1|2|44|44@RR         000000000.007915272s    000.00% 000.00% kworker@0011
0012|0000@1     Waiting 00|00|01|0|1|2|48|48@RR         000000000.013388112s    000.00% 000.00% kworker-H@0012
0014|0000@2     Running 00|00|01|0|1|4|00|00@RR         000000308.507188944s    099.67% 099.99% idle@0014
0015|0000@2     Waiting 00|00|01|0|1|4|62|62@FIFO       000000000.000010952s    000.00% 000.00% taskletd@0015
0017|0000@2     Waiting 00|00|01|0|1|4|44|44@RR         000000000.007978960s    000.00% 000.00% kworker@0017
0018|0000@2     Waiting 00|00|01|0|1|4|48|48@RR         000000000.012593160s    000.00% 000.00% kworker-H@0018
0020|0000@3     Running 00|00|01|0|1|8|00|00@RR         000000308.825292960s    099.77% 099.99% idle@0020
0021|0000@3     Waiting 00|00|01|0|1|8|62|62@FIFO       000000000.000011344s    000.00% 000.00% taskletd@0021
0023|0000@3     Waiting 00|00|01|0|1|8|44|44@RR         000000000.008045872s    000.00% 000.00% kworker@0023
0024|0000@3     Waiting 00|00|01|0|1|8|48|48@RR         000000000.024208920s    000.00% 000.00% kworker-H@0024
Current: 17/8192 | 0000 Suspend | 0000 Exiting | 0012 Waiting | 0000 Sleep | 0001 Ready | 0004 Running
Cpuidle: CPU0=99.96% CPU1=99.98% CPU2=99.99% CPU3=99.99%
ReadyCnt: CPU0=[1/5] CPU1=[0/4] CPU2=[0/4] CPU3=[0/4]
```

```
# mem
Buddy  Pools: 000009, Free 0x00001480 SingleAllocMax: 0x400
Bitmap Pools: 000008, Free 0x00003c60 SingleAllocMax: 0xfc0

page pool 0 info: size 0x10000000
page phys: 0x40000000, va: 0xffffffbfc0000000
page cnt: 65050/65536 (singleAllocMax: 32768)

page pool 1 info: size 0x5572000
page phys: 0x8028e000, va: 0xffffffc00028e000
page cnt: 21836/21874 (singleAllocMax: 16384)

kvma info: size 2000000000, va: 0xffffff9f80000000
l 0 Start 0xffffff9f80000000 Size 80000, Free 3d000, MaxOrder 17
l 1 Start 0xffffff9f80000000 Size 4000000, Free 3c80000, MaxOrder 25
l 2 Start 0xffffff9f80000000 Size 200000000, Free 1fc000000, MaxOrder 32
l 3 Start 0xffffff9f80000000 Size 2000000000, Free 1e00000000, MaxOrder 36
```

```
# irq
irq hwirq   parent  affinity    total-cnt       percpu-cnt      controller
1   29      nil     f           225731          CPU0: 54433     arm,gic
                                                CPU1: 54333
                                                CPU2: 59076
                                                CPU3: 57889
2   2       3       f           0               CPU0: 0         arm,gic,softint
                                                CPU1: 0
                                                CPU2: 0
                                                CPU3: 0
3   10      nil     f           745             CPU0: 186       arm,gic
                                                CPU1: 178
                                                CPU2: 184
                                                CPU3: 197
4   40      nil     f           24              CPU0: 24        arm,gic
                                                CPU1: 0
                                                CPU2: 0
                                                CPU3: 0
5   0(nil)  6       1           0               CPU0: 0         arm,gic,softint
                                                CPU1: 0
                                                CPU2: 0
                                                CPU3: 0
6   8(nil)  nil     1           0               CPU0: 0         arm,gic
                                                CPU1: 0
                                                CPU2: 0
                                                CPU3: 0
7   15      nil     f           138             CPU0: 135       arm,gic
                                                CPU1: 2
                                                CPU2: 0
                                                CPU3: 1
```

Misc

- ASLR is default enabled, it's better to disable it through **menuconfig** if you're debugging the issues related to memory fault.
- The default trace level of kernel is TRACE_LEVEL_INFO, you can change the CONFIG_TRACE_LEVEL through **menuconfig**.
- The default trace level of user is TRACE_LEVEL_ERROR, you can change it in **utrace.h**.
- The default layout of address spaces is defined in **map.h**, you can check and change them if needed.