Developer Guide

Security Starter Kit with i.MX 8X and OPTIGA™ TPM 2.0

Date: March 03, 2021 | Version 1.5

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ACRONYMS AND ABBREVIATIONS

Definition/Acronym/Abbreviation	Description
AI_ML board	Artificial intelligence and Machine Learning board featuring the NXP i.MX 8X MPU
AES	Advanced Encryption Standard
AHAB	Advanced High Assurance Boot
AWS	Amazon Web Services
BSP	Board Support Package
CA	Certificate Authority
CAAM	Cryptographic Acceleration and Assurance Module
CMS	Cryptographic Message Syntax
CSF	Command Sequence File
CSR	Certificate Signing Request
CST	Code Signing Tool
DCD	Device Configuration Data
GG	AWS Greengrass
OS	Operating System
OTP	One-Time Programmable
PKI	Public Key Infrastructure
SA	Signature Authority
SCFW	SCU Firmware
SDP	Serial Download Protocol
SECO	Security Controller
SPL	Secondary Program Loader
SRK	Super Root Key
SSK	Security Starter Kit
TPM	Trusted Platform Module
USB	Universal Serial Bus
TLS	Transport Layer Security
RSA	Rivest–Shamir–Adleman
IoT	Internet of Things
HSM	Hardware Security Module
PKCS#11	PKCS#11 (Public Key Cryptography Standards) defines an API to communicate with cryptographic security tokens such as smart cards, USB keys and HSMs
HW	Hardware
MQTT	Message Queuing Telemetry Transport
SSL	Secure Sockets Layer
SHA	Secure Hash Algorithm
SDK	Software Development Kit
ECC	Elliptic Curve Cryptography
ARN	Amazon Resource Name
SECO	Security Controller
FW	Firmware

NV RAM	Non Volatile Random Access Memory
API	Application Programming Interface
UUID	Universally Unique Identifier
SCP	Secure Copy Protocol
SCU	System Control Unit
IAM	AWS Identity and Access Management
TSS	TPM2 Software Stack

1 INTRODUCTION

1.1 Purpose of the Document

This guide describes - how to setup the OPTIGA™ TPM 2.0 on Arrow AI_ML based Yocto platform with integrated TPM driver and Amazon Greengrass support. This is a hardware layer security for AI_ML communication with AWS IoT Services.

1.2 Intended Audience

This document is for developers and end-users who want to use OPTIGA™ TPM 2.0, AI_ML, AWS services to develop a gateway solution enabled with hardware layer security.

1.3 Prerequisites

Below are the list of Hardware and Software needed to enable demonstration of the AWS GG and OPTIGA™ TPM 2.0 security,

- Security Starter Kit Setup will require the following:
    - AI_ML Board
    - Tresor Mezzanine board (with the OPTIGA™ TPM 2.0 installed)
    - SD-card -16GB
    - MicroUSB debug cable
    - Power Supply –
        - MEANWELL GST60A12-P1J
        - 5.5/2.1mm to 4.75/1.7mm cable DC plug converter
- Linux PC (Minicom for serial console)
- Internet connectivity (Wi-Fi/Ethernet) of Board and Linux PC should be on same Network

1.4 Scope of Detailed Design

Integration of AWS IoT Greengrass with OPTIGA™ TPM 2.0 to provide hardware-based endpoint device security. This integration ensures the use of private key to establish device identity, which is securely stored in tamper-proof hardware devices, which prevents the device from being compromised, impersonated and other malicious activities.

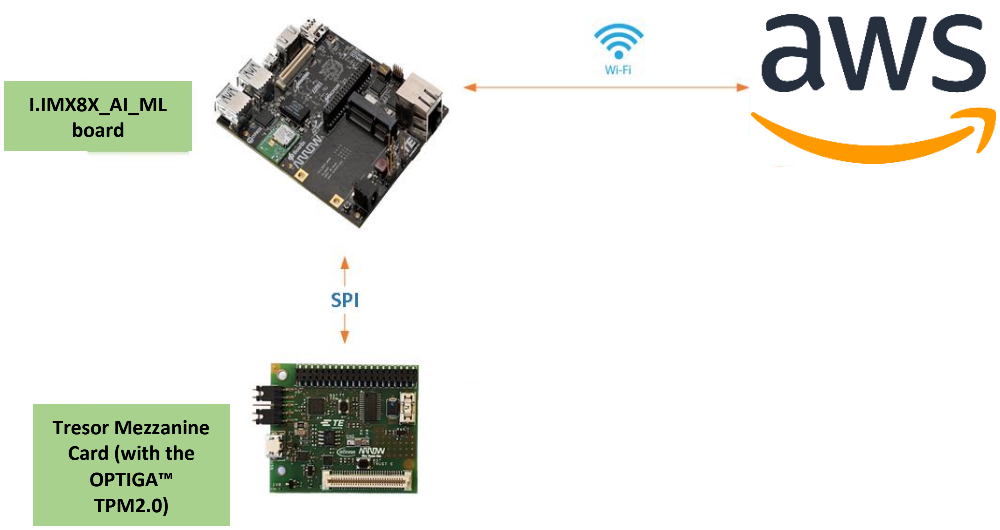


Figure 1: Security Starter Kit with I.MX 8X and OPTIGA™ TPM 2.0 Architecture.

2 ENVIRONMENT SETUP

1. Cloud Services – Amazon Web Services (User must have an AWS Account Credentials before using this Guide)
2. Gateway device - AI_ML Board AIML_BOARD
3. Hardware security device - Tresor Mezzanine Infineon OPTIGA™ TPM2.0. (TPM device swapped with the Infineon OPTIGA™ SLB 9670 TPM2.0)
4. Power Supply cable –12V-5A 60W AC/DC Power Supply & 2.1/1.7mm plug convertor
5. Debug Cable – MicroUSB debug cable
6. HOST PC – Linux as Operating System (Ubuntu 16.04)

3 HARDWARE SETUP

3.1 Hardware setup – Security Starter Kit with i.MX 8X and OPTIGA™ TPM 2.0Hardware connection between i.MX 8X (AI_ML board) and OPTIGA™ TPM2.0

The mezzanine will be mounted on top of the AI_ML board as shown in Figure 2. When the AI_ML board is powered-up, the Power LED on the OPTIGA™ TPM2.0 board turns on, indicating that the board is correctly connected. ***Users need to ensure the dip switch settings are configured for SD1 (0011). These settings are also on the silk screen of the board for your reference***.

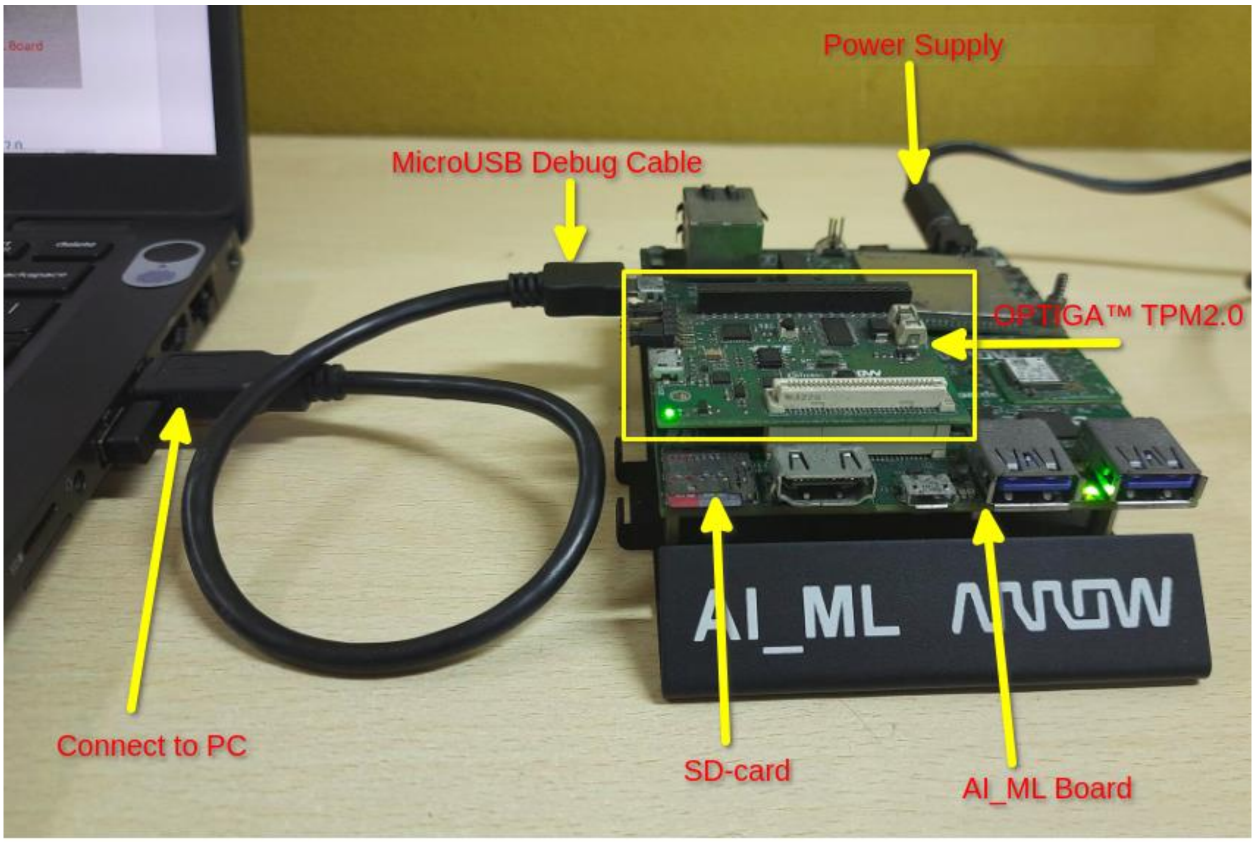


Figure 2: Hardware Connection Setup on AI_ML board

3.1.2 Powering up the Board

1. Take AI_ML Board, Insert the provided SD-card (Ensure SD-card is flashed with binaries first time)
2. Connect Micro USB Debug Cable on the Tresor Mezzanine board as shown in above Figure 2.
3. Connect Power-Adapter to AI_ML and the board is ready to use.
4. Open Serial terminal utility viz. Minicom on HOST PC to serially connect with the board

3.1.3 Open board's terminal- console (Minicom) on Linux PC

1. Before starting this step, the SD-card must be flashed with binary image and serial cable must be plugged into board as mentioned in hardware setup 3.1.1.
2. Connect serial cable's USB end to Linux PC's USB.
3. On Linux PC, Launch Minicom utility as shown below (For debugging purpose)

```
Linux-PC ~$ sudo  minicom –s
```

4. Set baud rate and other setting as per below
    a. Baud rate 115200
    b. Parity none
    c. hardware flow control/software flow control none
    d. Serial device /dev/ttyUSB0
    e. save setup as dfl

5. After the AI_ML board boots up, it will display below login console on Minicom terminal on Linux PC as shown below.
6. Username for board is "root" and the password is "root" (if asked for)

```
NXP i.MX Release Distro 4.14-sumo imx8qxpaiml ttyLP2

imx8qxpaiml login: root
Last login: Wed Sep 16 12:58:47 UTC 2020 on tty7
root@imx8qxpaiml:~#
```

4 SOFTWARE SETUP

4.1 I.MX_8X-SSK and OPTIGA™ TPM 2.0 Yocto Environment Setup

4.1.1 Pre-requisite

- Host PC (x86) having Linux Ubuntu 16.04 LTS installed (to build Yocto image)
- Basic understanding of Linux commands

4.1.2 Steps to build the BSP for the I.MX_8X-SSK and OPTIGA™ TPM 2.0

[**Note**: Default, Image will be available in the SD-card, But If user wants to install the new image again on the SD-card or in case the image gets corrupted, then below steps can be handy]

1. Download the SSK AI_ML release package from Arrow GitHub Security-Starter-Kits-i.MX_8X-SSK.zip on Linux HOST PC

2. Extract the Security-Starter-Kits-i.MX_8X-SSK.zip

```
Linux-PC $ unzip Security-Starter-Kits-i.MX_8X-SSK.zip
```

Extracting the zip file, one will find the below contents:

- i.MX_8X-SSK_Developers_Guide.pdf that has detailed description of all the components, examples and how to enable all features of the Kit.
- i.MX_8X-SSK Quick Start Guide.pdf
- iMX_8X_SSK_Pkg_Rel
    - Firmware_Image
    - SSK_AWS_Demo
    - SSK_Cert_And_Config
    - SSK_Suit_Configuration
    - Imx8x_Yocto_Build

1. Download meta-einfochips-SSK-V-1_0.tar.gz from Arrow GitHub and copy to iMX_8X_SSK_Pkg_Rel/Imx8x_Yocto_Build/.
2. Run the build script build_script_aiml.sh to complete Yocto environment setup.

```
Linux-PC $ cd iMX_8X_SSK_Pkg_Rel/Imx8x_Yocto_Build/
Linux-PC $./build_script_aiml.sh
```

3. Please note that, if you re-build any module then it is better to re-build all modules, which are dependent on that module. For example, if you change anything in Linux kernel code and rebuild it using above commands then you must need to re-build kernel-module-laird, imx-gpu-sdk etc. packages to avoid conflicts.

```
Linux-PC $: bitbake <PACKAGE_NAME> -c cleanall
Linux-PC $: bitbake <PACKAGE_NAME>

Linux-kernel
```

```
Linux-PC $: bitbake linux-imx -c cleanall
Linux-PC $: bitbake linux-imx (Build Linux kernel only)

Same way
Linux-PC $: bitbake u-boot-imx -c cleanall
Linux-PC $: bitbake u-boot-imx (Build UBoot code only)
```

4. When build is successful, the final SD-card image resides at below location:
   bld-xwayland-aiml/tmp/deploy/images/imx8qxpaiml/ copied to /Firmware_Image

5. Filename should be fsl-image-qt5-imx8qxpaiml.sdcard.bz2 which is soft link of original build image file fsl-image-qt5-imx8qxpaiml-<TIMESTAMP>.rootfs.sdcard.bz2

[Note: Please refer the Bitbake User Manual for better understanding of bitbake files, recipes and layers as well as options to build an image.]

6. Once Yocto build is complete. Create SD-card image.

7. Navigate to the directory "Firmware_Image" in order to find built SD-card image.

```
Linux-PC $cd iMX_8X_SSK_Pkg_Rel/Firmware_Image /
Linux-PC $bunzip2 -dkf  fsl-image-qt5-imx8qxpaiml-TIMESTAMP.rootfs.sdcard.bz2
Linux-PC $ ls /dev/<device>
```

8. Flash the SD-card using below command

```
Linux-PC $sudo dd if= fsl-image-qt5-imx8qxpaiml-TIMESTAMP .rootfs.sdcard of=/dev/<device> bs=1M conv=fsync status=progress && sync
```

9. Unmount and eject the SD-card from the Linux PC.
10. Re-inserting the SD-card to Linux PC, will mount below partitions, verify using below command

```
Linux-PC $ sudo lsblk

    |–mmcblk0p1 179:1  0  64M 0 part /media/<username>/Boot imx8qx
    └─mmcblk0p2 179:2  0  7G   0 part /media/<username>/rootfs_id
```

11. Copy below listed files to file system i.e. SSK_Suit_package

```
• Linux-PC $  sudo cd iMX_8X_SSK_Pkg_Rel

• Linux-PC $ sudo cp -r SSK_AWS_Demo/ SSK_Suit_Configuration/
  /media/<username>/rootfs_id/home/root/
```

- Linux-PC $ sudo cp -r SSK_Cert_And_Config/AWS_Config/openssl.cnf /media/<username>/rootfs_id/etc/ssl/
- Linux-PC $ sudo cp -r SSK_Cert_And_Config/AWS_Config/config.json /media/<username>/rootfs_id/greengrass/config/
- Linux-PC $ sudo cp -r SSK_Cert_And_Config/AWS_ROOTCA/rootCA.key /media/<username>/rootfs_id/greengrass/certs/
- Linux-PC $ sudo cp -r SSK_Cert_And_Config/AWS_ROOTCA/rootCA.pem /media/<username>/rootfs_id/greengrass/certs/
- Linux-PC $ sudo cp -r SSK_Cert_And_Config/AWS_ROOTCA/root.ca.pem /media/<username>/rootfs_id/greengrass/certs/
- Linux-PC $ sudo cp -r SSK_Suit_Configuration/Tpm_Measured_Boot/Measured_boot.sh /media/<username>/rootfs_id/etc/init.d/
- Linux-PC $ sudo cp -r SSK_Suit_Configuration/Tpm_Measured_Boot/rc-local.service /media/<username>/rootfs_id/etc/systemd/system/
- Linux-PC $ sudo cp -r SSK_Suit_Configuration/Tpm_Measured_Boot/rc.local /media/<username>/rootfs_id/etc/
- Linux-PC $ sync

12. The SD-card is now ready for use on the AI_ML board
13. Plug the SD-card in the AI_ML board and power up the board. The board will boot, it will display boot up logs, and finally ask for login.

4.2 Keys and certificates information

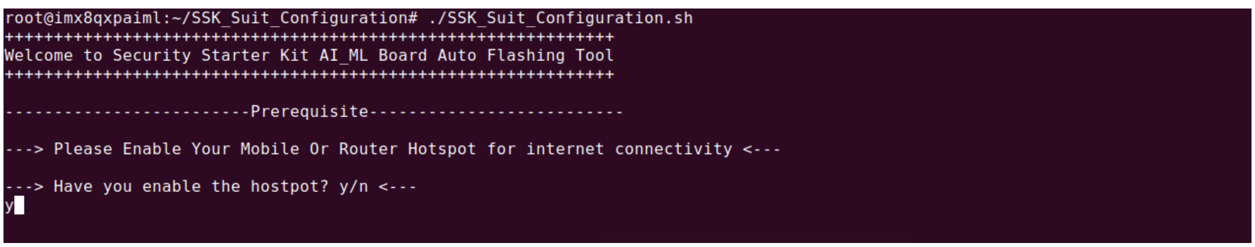
- Preloaded one root certificate (associated private key provided as a file) - rootCA.pem
- One root private key - rootCA.key
- One AWS IoT root certificate - root.ca.pem
- Key pairs associated device certificate Pre-Flashed into Trusted Platform Module Chip – Inside HSM
- One Device certificate signed with the root private key and the associated private key needed for TLS mutual authentication with AWS IoT – [generated using SSK_Suit_Configuration.sh]

4.3 OPTIGA™ TPM2.0 Setup Script

After successful boot-up of the AI_ML board, the user needs to setup the hardware security chip OPTIGA™ TPM2.0. This Setup script will setup install prerequisite packages and TPM configuration (i.e. create Keypair, device certificate and store in OPTIGA™ TPM2.0).

1. Enable the Wi-Fi internet connectivity using mobile hotspot or router.
2. Use Minicom console to run the script, as mentioned below

```
root@imx8qxpaiml:~#cd /greengrass/certs
root@imx8qxpaiml:~#openssl genrsa -out rootCA.key 2048
root@imx8qxpaiml:~#openssl req -x509 -new -nodes -key rootCA.key -sha256 -days 7000 -out
rootCA.pem -subj /C="IN"/ST="GUJ"/L="AHMEDABAD"/O="Arrow"/OU="eic"
root@imx8qxpaiml:~# cd ~/SSK_Suit_Configuration
root@imx8qxpaiml:~#./SSK_Suit_Configuration.sh
```



```
root@imx8qxpaiml:~/SSK_Suit_Configuration# ./SSK_Suit_Configuration.sh
+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
Welcome to Security Starter Kit AI_ML Board Auto Flashing Tool
+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

-------------------------Prerequisite-------------------------

---> Please Enable Your Mobile Or Router Hotspot for internet connectivity <---

---> Have you enable the hostpot? y/n <---
y
```

3. If internet connectivity is enabled, press "Y". This will fetch the SSID of Wi-Fi list. Enter the SSID name and password details, example shown as below:

```
---> [WIFI] List of available Wifi devices in Range... <---
        SSID: ei-SecureWiFi
        SSID: ei-GuestWiFi
        SSID: Sai Financial
        SSID: ei-SecureWiFi
        SSID: ei-GuestWiFi
        SSID: TP-Link_8A6D
        SSID: KVMS_Private
        SSID: Echo
        SSID:
                 * SSID List
        SSID: haresh.vithlani
        SSID:
                 * SSID List
        SSID: KVMS_EIC
        SSID: Rahul
        SSID: abzaveri
        SSID: hello
        SSID: ei-SecureWiFi
        SSID: ei-GuestWiFi
        SSID: DIRECT-bd-HP M227f LaserJet
        SSID: TP-Link_8A6C_5G
        SSID: ORBI28
                 * SSID List
        SSID: ORBI70
                 * SSID List
        SSID: ei-SecureWiFi
        SSID: ei-GuestWiFi
        SSID:
        SSID: ei-SecureWiFi
        SSID: ei-GuestWiFi

---> Can you see your wifi devices:SSID? y/n <---
y
---> Please Enter the Name of your Wifi-Device SSID <---
hello
---> Can you please Provide the Password of your Wifi-Device <---
12341234
Successfully initialized wpa_supplicant
```

4. Now, it will start installing the package. If running for the first time it will take ~20 minutes.

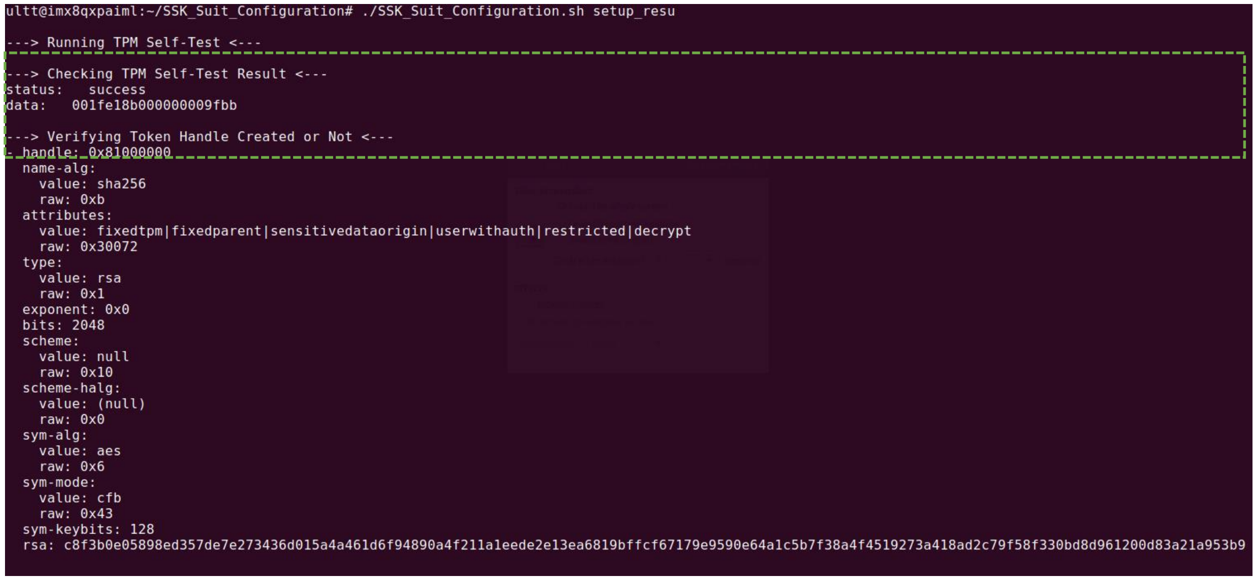
```
---> Installing Required Python Packages for Implementing Security Sectup on Board with TPM2.0 <---

---> Process will take Time...Please Wait for 20mins <---
```

5. After completion of script, it creates Keypair and device certificate using TPM.

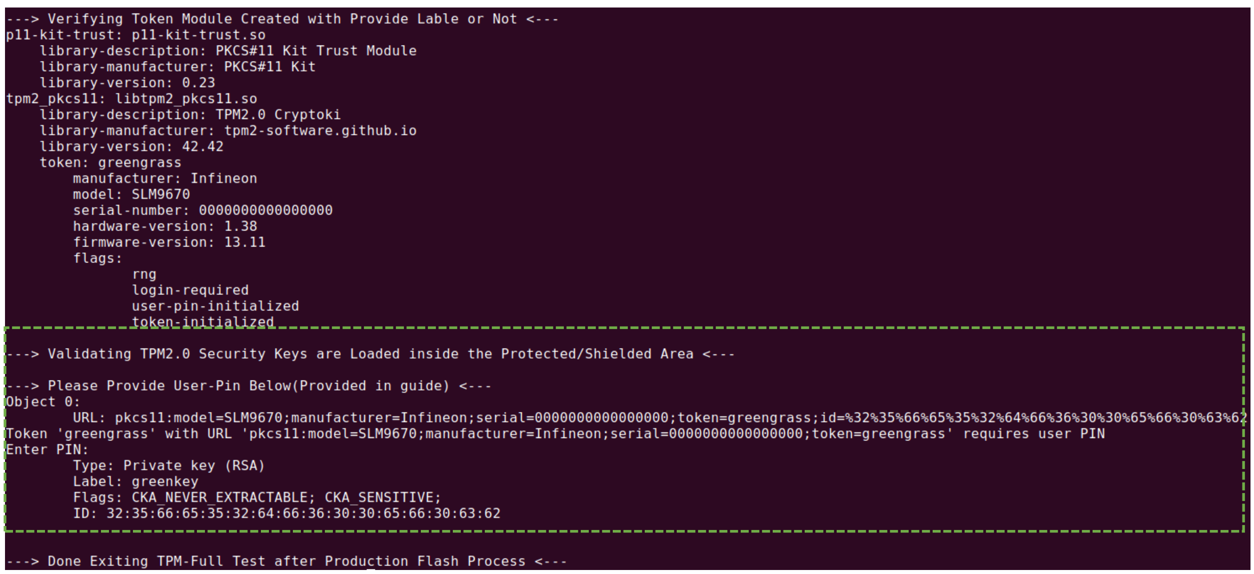
```
---> Create Device Certificates Signed By RootCA <---
Signature ok
subject=/C=IN/ST=GUJ/L=AHM/O=Arrow/OU=eic/CN=SSK
Getting CA Private Key

---> TPM2.0-Device Cerificate Created Sucessfully <---
---> Board is ready to Use for Demo <---
```

6. Verify the Steps using below commands [Enter #PIN: 1234]

```
root@imx8qxpaiml:~# ./SSK_Suit_Configuration.sh setup_result
```



```
ultt@imx8qxpaiml:~/SSK_Suit_Configuration# ./SSK_Suit_Configuration.sh setup_resu

---> Running TPM Self-Test <---

---> Checking TPM Self-Test Result <---
status:   success
data:   001fe18b000000009fbb

---> Verifying Token Handle Created or Not <---
- handle: 0x81000000
  name-alg:
    value: sha256
    raw: 0xb
  attributes:
    value: fixedtpm|fixedparent|sensitivedataorigin|userwithauth|restricted|decrypt
    raw: 0x30072
  type:
    value: rsa
    raw: 0x1
  exponent: 0x0
  bits: 2048
  scheme:
    value: null
    raw: 0x10
  scheme-halg:
    value: (null)
    raw: 0x0
  sym-alg:
    value: aes
    raw: 0x6
  sym-mode:
    value: cfb
    raw: 0x43
  sym-keybits: 128
  rsa: c8f3b0e05898ed357de7e273436d015a4a461d6f94890a4f211a1eede2e13ea6819bffcf67179e9590e64a1c5b7f38a4f4519273a418ad2c79f58f330bd8d961200d83a21a953b9
```



```
---> Verifying Token Module Created with Provide Lable or Not <---
p11-kit-trust: p11-kit-trust.so
    library-description: PKCS#11 Kit Trust Module
    library-manufacturer: PKCS#11 Kit
    library-version: 0.23
tpm2_pkcs11: libtpm2_pkcs11.so
    library-description: TPM2.0 Cryptoki
    library-manufacturer: tpm2-software.github.io
    library-version: 42.42
    token: greengrass
        manufacturer: Infineon
        model: SLM9670
        serial-number: 0000000000000000
        hardware-version: 1.38
        firmware-version: 13.11
        flags:
               rng
               login-required
               user-pin-initialized
               token-initialized

---> Validating TPM2.0 Security Keys are Loaded inside the Protected/Shielded Area <---

---> Please Provide User-Pin Below(Provided in guide) <---
Object 0:
        URL: pkcs11:model=SLM9670;manufacturer=Infineon;serial=0000000000000000;token=greengrass;id=%32%35%66%65%35%32%64%66%36%30%30%65%66%30%63%62
Token 'greengrass' with URL 'pkcs11:model=SLM9670;manufacturer=Infineon;serial=0000000000000000;token=greengrass' requires user PIN
Enter PIN:
        Type: Private key (RSA)
        Label: greenkey
        Flags: CKA_NEVER_EXTRACTABLE; CKA_SENSITIVE;
        ID: 32:35:66:65:35:32:64:66:36:30:30:65:66:30:63:62

---> Done Exiting TPM-Full Test after Production Flash Process <---
```

Additional Steps:

[Note: If user wants to clear the TPM then below steps will help for debugging]

7. TPM Clear command
   In case of some mistakes when following the steps or any error occurred while configuring setup, the User can reset the TPM2.0 with below command.

```
root@imx8qxpaiml:~# ./SSK_Suit_Configuration.sh tpm_clear
```

```
root@imx8qxpaiml:~/SSK_Suit_Configuration# ./SSK_Suit_Configuration.sh tpm_clear
---> TPM2.0 Cleared with Tokens and Labels <---
0x1500016:
---> Clearing Done Exiting <---
root@imx8qxpaiml:~/SSK_Suit_Configuration# 
```

8. If TPM is clear, then user will get below logs. Again, execute the above steps from 1 to 6 for setup again as described in 4.3 else follow the section 4.4.1 and 4.4.2

```
ultt@imx8qxpaiml:~/SSK_Suit_Configuration# ./SSK_Suit_Configuration.sh setup_res

---> Running TPM Self-Test <---

---> Checking TPM Self-Test Result <---
status:   success
data:   001fe18b000000009fbb

---> Verifying Token Handle Created or Not <---

---> Verifying Token Module Created with Provide Lable or Not <---
p11-kit-trust: p11-kit-trust.so
    library-description: PKCS#11 Kit Trust Module
    library-manufacturer: PKCS#11 Kit
    library-version: 0.23

---> Validating TPM2.0 Security Keys are Loaded inside the Protected/Shielded Area <---

---> Please Provide User-Pin Below(Provided in guide) <---
No matching objects found

---> Done Exiting TPM-Full Test after Production Flash Process <---
root@imx8qxpaiml:~/SSK_Suit_Configuration# 
```

4.4 TLS Mutual Authentication and Session Establishment Using H/w Security of TPM With Amazon AWS IOT

Amazon cloud allows customers to use device certificates signed and issued by their own certificate authority (CA) to connect and authenticate with AWS IoT. This is an alternative to using certificates generated by AWS IoT and fits better for customers' needs. This method is used by "things" using MQTT protocol. MQTT is using TLS as a secure transport mechanism. In IoT, each "thing" needs to be uniquely identified by the Cloud application and that is realized by using device certificates as identifiers.

When establishing TLS connectivity, AWS IoT authenticates the connecting device by extracting the device certificate and verifying its signature against a customer preloaded root certificate. Similarly, the device needs to verify the server certificate against the stored AWS IoT root certificate to confirm the authenticity of the server to which it connects. TLS mutual authentication requires the device to prove the ownership of its private key used to form the device certificate and this is being done by signing some data packets with the private key.

The AI_ML Gateway with OPTIGA™ TPM2.0 facilitates the creation and signing of a device certificate. The device certificate is intended for establishing TLS connections with mutual authentication. The Kit provides an example of how to use the device certificate and OPTIGA™ TPM2.0 based crypto for establishing a TLS connection with Amazon AWS IoT (usually used for running MQTT protocol that runs on top of TLS).

The example requires the user to create an AWS account, create an OEM Root CA and upload it to AWS. The Device Certificate needs to be signed with the private key that created the OEM Root CA so the two certificates are chained. It needs to be noted that Amazon AWS does not allow the activation of the same OEM Root CA for multiple AWS accounts.

The example here guides the user to perform the following steps:

- create an AWS Custom CA, register the Custom CA in AWS, provide verification to AWS and create an AWS Device Certificate.
- Save the created AWS Custom CA and AWS Device key and cert in OPTIGA™ TPM2.0.
- This way the AWS CAs and the AWS Device Certificate are unique and can be used with AWS for the Evaluation Kit by multiple users

To set and test the TLS mutual authentication and connectivity to AWS IoT, users will generate their own AWS Custom CA private key and certificate and AWS device key and certificate, which must be ECDSA 256 (actively using RSA-256 Technique).

Cert/key	Name of cert/key exposed by OPTIGA™ TPM and AI_ML	Description
Cloud IoT Root CA	root.ca.pem	Root CA of the Cloud IoT. It is used for TLS mutual authentication.
Gateway Root Certificate/Key	rootCA.pem rootCA.key	Gateway Root Certificate. For the Evaluation Kit this cert is predefined. The associated private key is provided as a file for execution of the payload verification example application
Gateway Verification Certificate/Key	verificationCert.crt verificationCert.key	Gateway Verification Certificate. For the Evaluation Kit this cert is predefined. The associated private key is provided as a file for execution of the payload verification of Root Certificate with provided AWS
Gateway/Device Private Key	Stored securely under TPM	Created and Stored under PKCS11 Handle with TPM Accessible only
Gateway/Device Certificate	aws_device_cert.pem	Device Credentials are accessible with private key being verified through TPM

Table 1: Preloaded Keys and Certificates

The AWS cloud certificate is preloaded in the AWS.
The example uses the following keys and certificates:

1. AWS IoT Root Certificate: Comes preloaded with AWS
2. AWS Custom Gateway CA Key: The user generates this private key. It is used to sign the AWS Device Certificate and to complete the AWS Custom CA Certificate registration process with AWS IoT

3. **AWS Custom Gateway CA Certificate**: The user creates this certificate and using the openssl tool. This certificate needs to be uploaded to the AWS IoT cloud
4. **AWS Device Private Key:** Private key is generated by user stored inside TPM securely, not exposed to outside world
5. **AWS Device Certificate:** The user creates this certificate. It must be created and signed with the AWS Custom Gateway CA Key. It is used during the AWS device registration step.

[**Note:** If you followed the steps as per **Section4.3**- OPTIGA™ TPM2.0 Setup Script then please Ignore below **section 4.4.1, 4.4.2**]

4.4.1 Linux Environment: Generate the required keys and certificate

To use your own X.509 device certificates, it is essential to register a CA certificate with AWS IoT. The CA certificate can then be used to sign device certificates. You can register up to 10 CA certificates with the same subject field per AWS account per AWS region. This allows you to have more than one CA - sign your device certificates.

[Note: The registered CA certificate must sign Device certificates. It is common for a CA certificate to be used to create an intermediate CA certificate. If you are using an intermediate certificate to sign your device certificates, you must register the intermediate CA certificate. Use the AWS IoT root CA certificate when you connect to AWS IoT even if you register your own root CA certificate. The AWS IoT root CA certificate is used by a device to verify the identity of the AWS IoT servers]

Earlier, AWS IoT released support for customers in case user wants to use their own device certificates signed by their preferred Certificate Authority (CA). This is in addition to the support for AWS IoT generated certificates. The CA certificate is used to sign and issue device certificates, while the device certificates are used to connect a client to AWS IoT. Certificates provide strong client-side authentication for constrained IoT devices. During TLS handshake, the server authenticates the client using the X.509 certificate presented by the client.

With this feature, customers with existing devices in the field or new devices with certificates signed by a CA other than AWS IoT can seamlessly authenticate with AWS IoT. It also provides manufacturers the ability to provision device certificates using their current processes and then register those device certificates to AWS IoT. For example, if a customer's manufacturing line lacks internet connectivity; they can provision their devices offline with their own CA issued certificates and later register them with AWS IoT.

This exercise will walk you through an end-to-end process of setting up a client that uses a device certificate signed by your own CA. First, you will generate a CA certificate that will be used to sign your device certificate. Next, you will register the CA certificate and then register the device certificates. After these steps, your device certificate will be ready to connect AWS IoT service.

4.4.1.1 AWS Custom Gateway CA Creation

Let us begin by creating your first sample CA certificate using OpenSSL in a terminal. In reality, you will have the signing certificates issued by your CA vendor in the place of this sample CA. This sample CA certificate is used later in the walkthrough to sign a device certificate that will be registered with AWS IoT:

[Note: If you do not have a CA certificate, you can use OpenSSL tool]

To create a CA certificate

1. Generate a key pair on board at **/greengrass/certs**.

```
root@imx8qxpaiml:~# cd /greengrass/certs/
root@imx8qxpaiml:~# openssl genrsa -out rootCA.key 2048
```

2. Use the private key from the key pair to generate a CA certificate.

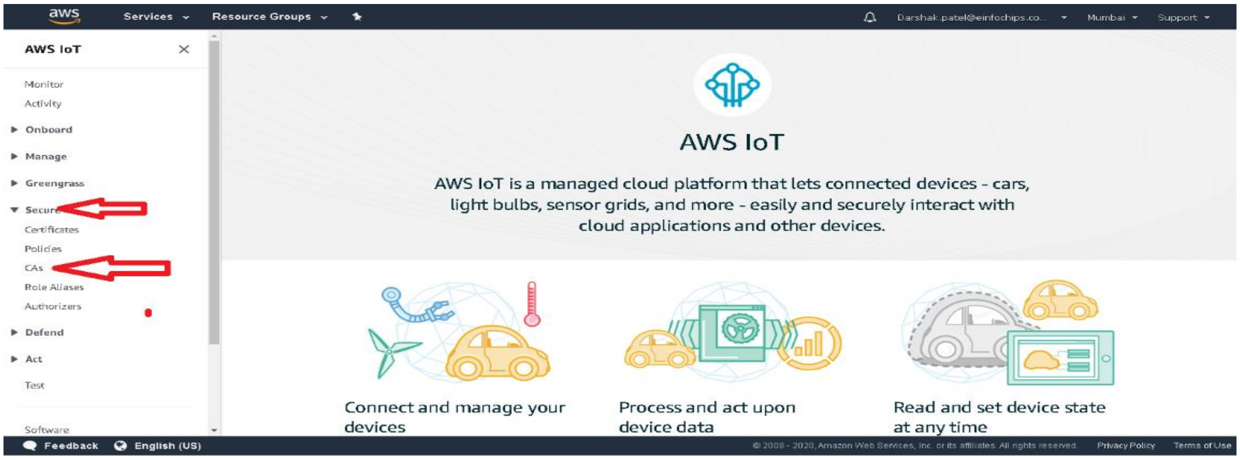
```
root@imx8qxpaiml:~# openssl req -x509 -new -nodes -key rootCA.key -sha256 -days 1024 -out
rootCA.pem
```

4.4.1.2 Registering Your CA Certificate

[Note: A CA certificate cannot be registered with more than one account in the same AWS Region. However, a CA certificate can be registered with more than one account if the accounts are in different AWS Regions. A CA certificate is used to register Device certificate, which are signed by CA certificate.]

To register a CA certificate

Get a registration code from AWS IoT. This code is used as the Common Name of the private key verification certificate. One can retrieve the registration code using the AWS CLI or from the **AWS IoT Console >> SECURE >> CA >> Register Certificate section.**



Register a CA certificate

To use your own X.509 certificates, you must register a CA certificate with AWS IoT. You must prove you own the private key associated with the CA certificate by creating a private key verification certificate. The CA certificate can then be used to sign device certificates. You can register up to 10 CA certificates with the same subject field and public key per AWS account. This allows you to have more than one CA sign your device certificates.

Step 1: Generate a key pair for the private key verification certificate

```
openssl genrsa -out verificationCert.key 2048
```

Step 2: Copy this registration code

```
1c88ceefdaf69a90f579e3abe85784b1c6d5b8e40c10743cfcc59fd28e432e56
```

1. Generate a key pair for the private key verification certificate:

```
root@imx8qxpaiml:~# openssl genrsa -out verificationCert.key 2048
```

2. Create a CSR for the private key verification certificate. Set the Common Name field of the certificate to your registration code. Fetched from above AWS IoT Console >> SECURE >> CA >> Register Certificate section.

```
root@imx8qxpaiml:~# openssl req -new -key verificationCert.key -out verificationCert.csr
```

User needs update some information, including the Common Name for the certificate.

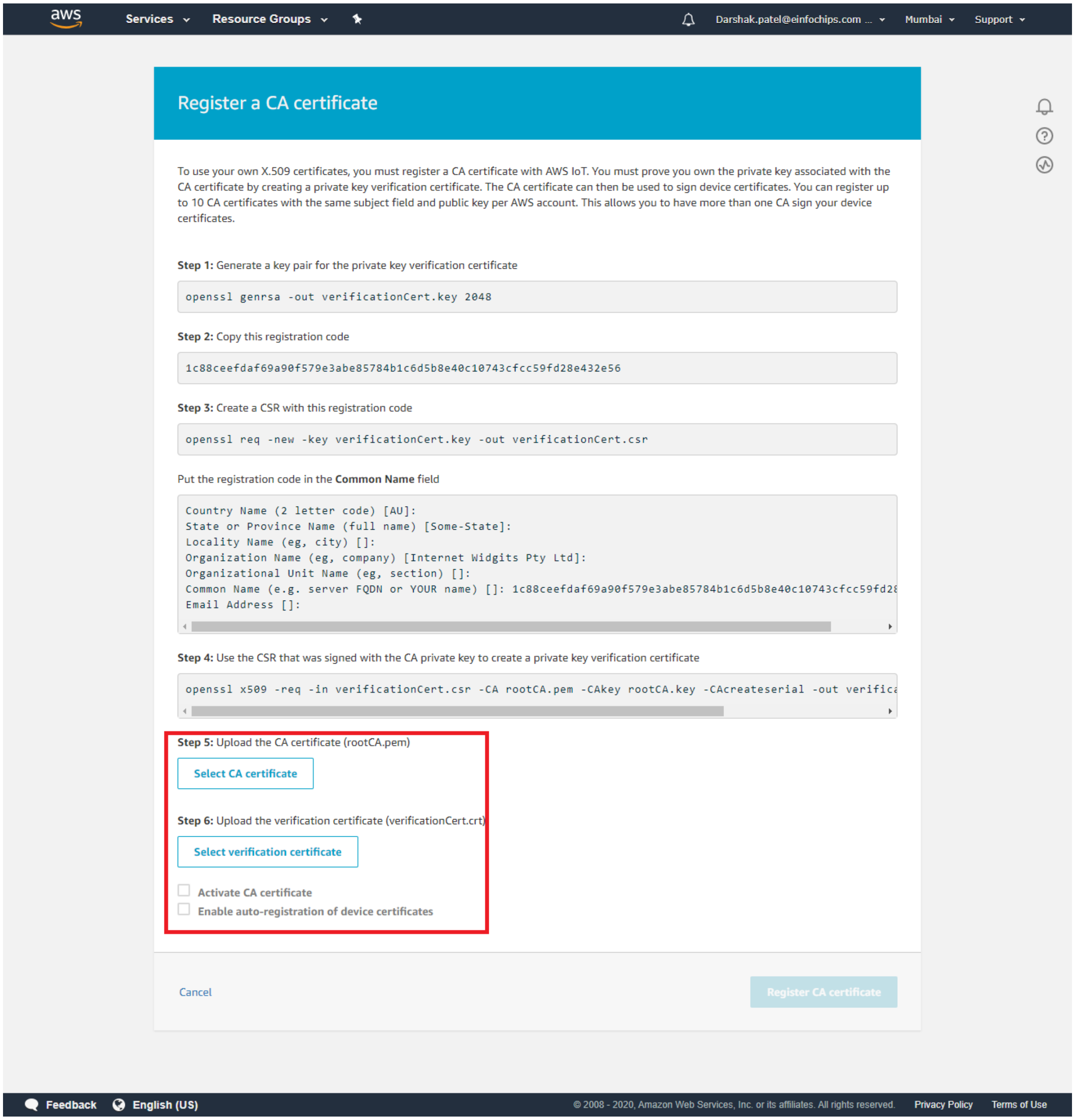
Country Name (2-letter code) [AU]:
State or Province Name (full name) []:
Locality Name (for example, city) []:
Organization Name (for example, company) []:
Organizational Unit Name (for example, section) []:
Common Name (e.g. server FQDN or YOUR name)

[]: XXXXXXXXXXXMYREGISTRATIONCODEXXXXXX
Email Address []:

3. Use the CSR to create a private key verification certificate:

```
root@imx8qxpaiml:~#  openssl x509 -req -in verificationCert.csr -CA rootCA.pem -CAkey rootCA.key -CAcreateserial -out verificationCert.crt -days 500 -sha256
```

4. In the navigation pane, go to Secure option on IoT Console then select Secure >> CA >> "Register your CA certificate", and upload your sample CA certificate and verification certificate:



4.4.2 Linux Environment: Secure Device Certificate and Private Key Gen

You can use a CA certificate, registered with AWS IoT, to create a device certificate. The device certificate must register with AWS IoT before use

1. Changes have been made in AIML-meta-security build image
2. Check if any persistent handle is already present with OPTIGA™ TPM2.0.

```
root@imx8qxpaiml:~# tpm2_listpersistent
- handle: 0x81000000
  name-alg:
    value: sha256
    raw: 0xb
  attributes:
    value: fixedtpm|fixedparent|sensitivedataorigin|userwithauth|restricted|decrypt
    raw: 0x30072
.
.
.
```

3. To clear the earlier token and handle inside OPTIGA™ TPM2.0 Chipset, use the command

```
root@imx8qxpaiml:~# tpm2_evictcontrol -a o -c 0x81000000 -p 0x81000000
```

4. Install python packages.

```
root@imx8qxpaiml:~# pip install --upgrade pip; pip install pyyaml==5.3.1 ; sleep 1 ; pip install cryptography==2.9.2 ; sleep 1 ; pip install paramiko==2.7.2 ; sync ;sync
```

5. Clone the script file to board

```
root@imx8qxpaiml:~# git clone https://github.com/tpm2-software/tpm2-pkcs11
root@imx8qxpaiml:~# cd tpm2-pkcs11/
root@imx8qxpaiml:~# tpm2-pkcs11/# git checkout a82d0709c97c88cc2e457ba111b6f51f21c22260
```

6. Run the script to generate keys and token inside TPM2.0 inside given directory.

```
root@imx8qxpaiml:~# cd ~/tpm2-pkcs11/tools

root@imx8qxpaiml:~# ./tpm2_ptool.py init --pobj-pin=1234 --path=/opt/tpm2-pkcs11/

Created a primary object of id: 1

root@imx8qxpaiml:~# ./tpm2_ptool.py addtoken --pid=1 --pobj-pin=1234 --sopin=1234 --userpin=1234 --label=greengrass --path=/opt/tpm2-pkcs11/

Created token label: greengrass

root@imx8qxpaiml:~# ./tpm2_ptool.py addkey --algorithm=rsa2048 --label=greengrass --userpin=1234 --key-label=greenkey --path=/opt/tpm2-pkcs11/

Added key as label: "greenkey"
```

7. Create Soft link to the resource manager libraries for listing token from OPTIGA™ TPM2.0 and displaying it on board's console.

```
root@imx8qxpaiml:~# cd /usr/lib/
root@imx8qxpaiml:/usr/lib# ln -s libtss2-tcti-tabrmd.so.0  libtss2-tcti-tabrmd.so
```

8. To check the URL's of token generated, p11tool and p11-kit is needed along with other packages opensc, Use the command **p11-kit list-modules** to list the HSI modules available with tokens.

```
root@imx8qxpaiml:~# p11-kit list-modules
p11-kit-trust: p11-kit-trust.so
    library-description: PKCS#11 Kit Trust Module
    library-manufacturer: PKCS#11 Kit
    library-version: 0.23
  tpm2_pkcs11: libtpm2_pkcs11.so
    library-description: TPM2.0 Cryptoki
    library-manufacturer: tpm2-software.github.io
    library-version: 42.42
    token: greengrass
        manufacturer: Infineon
        model: SLB9670
        serial-number: 0000000000000000
        hardware-version: 1.16
        firmware-version: 7.40
        flags:
            rng
            login-required
            user-pin-initialized
            token-initialized
```

9. Use command "p11tool --list-tokens" to see the token with its URL.

```
root@imx8qxpaiml:~# p11tool --list-tokens
Token 0:
    URL:pkcs11:model=SLB9670;manufacturer=Infineon;serial=0000000000000000;token=greengr
ass
        Label: greengrass
        Type: Hardware token
        Manufacturer: Infineon
        Model: SLB9670
        Serial: 0000000000000000
        Module: libtpm2_pkcs11.so
```

10. Use command "p11tool --list-privkeys pkcs11:manufacturer=Infineon" to see the PKCS listing OPTIGA™ TPM2.0 private and public keys.

Note: Provide PIN: 1234 if asked

```
root@imx8qxpaiml:~# p11tool --list-privkeys pkcs11:manufacturer=Infineon
	Object 0:
URL:
pkcs11:model=SLB9670;manufacturer=Infineon;serial=0000000000000000;token=greengrass;id=%36
%36%37%36%30%39%61%62%36%65%65%36%39%34%33%30;object=greenkey
	Token 'greengrass' with URL
'pkcs11:model=SLB9670;manufacturer=Infineon;serial=0000000000000000;token=greengrass'
requires user PIN
	Enter PIN:
		Type: Private key (RSA)
		Label: greenkey
		Flags: CKA_NEVER_EXTRACTABLE; CKA_SENSITIVE;
		ID: 36:36:37:36:30:39:61:62:36:65:65:36:39:34:33:30
```

11. Creation of soft link to "libpkcs11.so"

```
root@imx8qxpaiml:~# cd /usr/lib/engines/
root@imx8qxpaiml:~# ln -s  pkcs11.so libpkcs11.so
root@imx8qxpaiml:~# export PKCS11_MODULE_PATH=/usr/lib/libtpm2_pkcs11.so
```

12. Edit openssl.conf for enabling PKCS11 interface for TPM (Edit only highlighted points)

```
root@imx8qxpaiml:~# vi  /etc/ssl/openssl.conf
#
# OpenSSL example configuration file.
# This is mostly being used for generation of certificate requests.
#

# This definition stops the following lines choking if HOME isn't
# defined.
HOME		= .
RANDFILE	= $ENV::HOME/.rnd

openssl_conf = openssl_init

# Extra OBJECT IDENTIFIER info:
#oid_file	= $ENV::HOME/.oid
oid_section	= new_oids

```

13. Edit below contents at <u>bottom</u> of openssl.conf file, open /etc/ssl/openssl.conf

```
[openssl_init]
engines=engine_section

[engine_section]
pkcs11 = pkcs11_section
```

```
[pkcs11_section]
engine_id = pkcs11
dynamic_path = /usr/lib/engines/libpkcs11.so
MODULE_PATH = /usr/lib/pkcs11/libtpm2_pkcs11.so
init = 0
```

14. Generate Certificate Signing Request with openssl

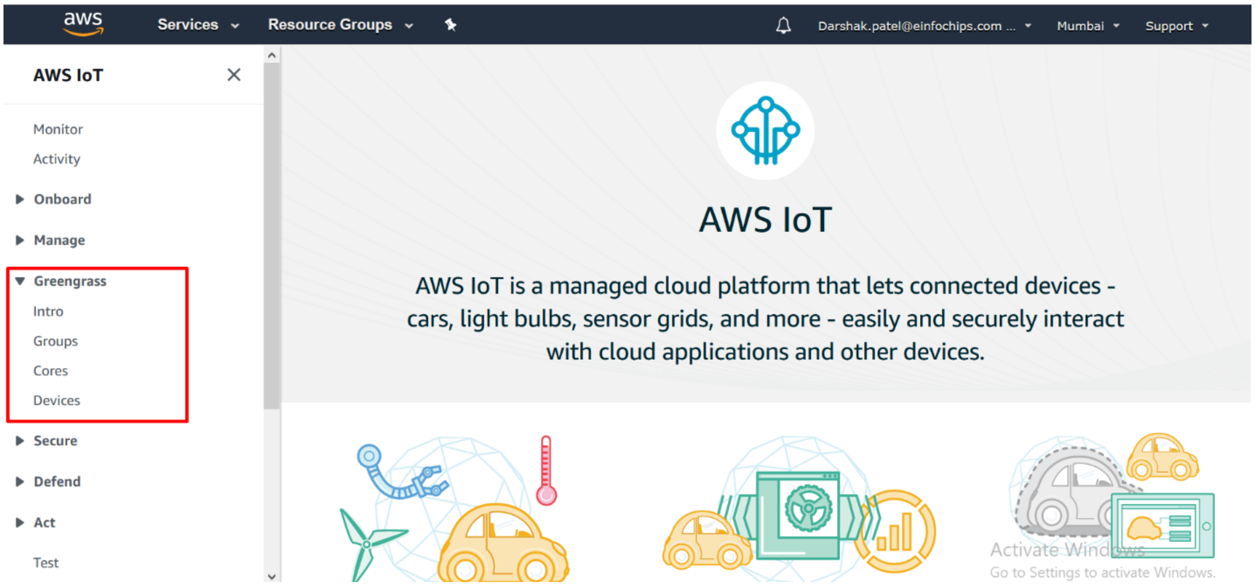
```
root@imx8qxpaiml:~# openssl req -engine pkcs11 -new –key
"pkcs11:model=SLB9670;manufacturer=Infineon;token=greengrass;object=greenkey;type=private;pin-
value=1234" -keyform engine -out /greengrass/certs/deviceCert.csr

Country Name (2 letter code) [AU]:IN
State or Province Name (full name) [Some-State]:GUJARAT
Locality Name (eg, city) []:AHM
Organization Name (eg, company) [Internet Widgits Pty Ltd]:EIC2
Organizational Unit Name (eg, section) []:KB
Common Name (e.g. server FQDN or YOUR name) []:SSK
Email Address []:

Please enter the following 'extra' attributes
to be sent with your certificate request
A challenge password []:1234
An optional company name []:ARROW
```

15. Registering Device Certificates manually

```
root@imx8qxpaiml:~#cd /greengrass/certs/
root@imx8qxpaiml:~# openssl x509 -req -in deviceCert.csr -CA rootCA.pem -CAkey rootCA.key -
CAcreateserial -out aws_device_cert.pem  -days 500 -sha256
```

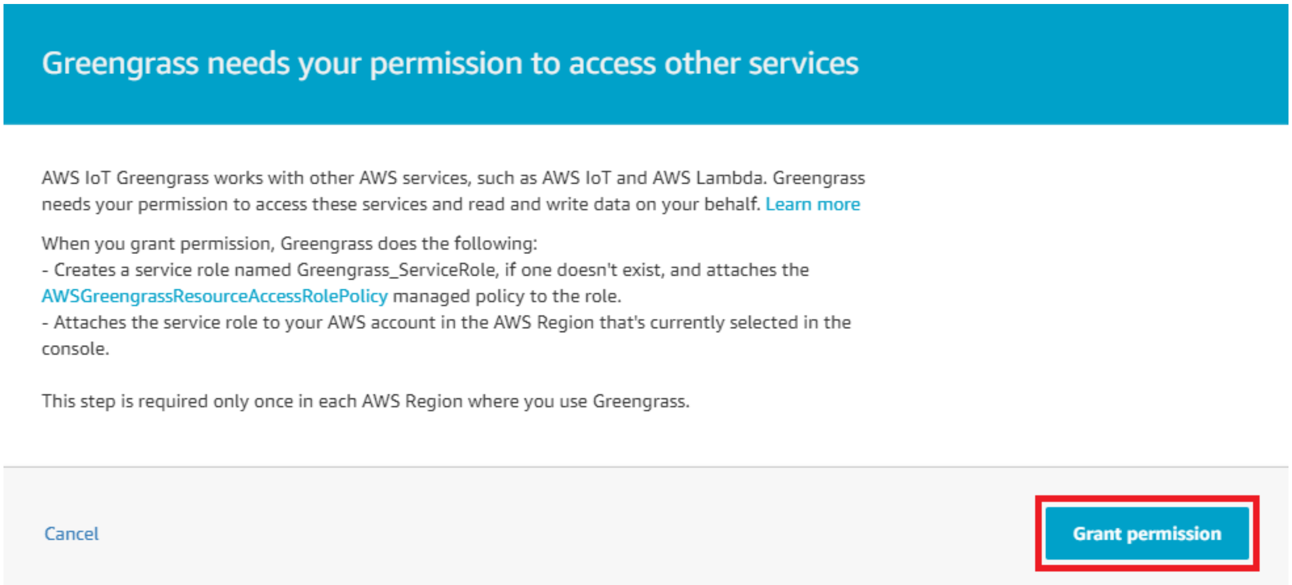
4.5 AWS Greengrass Group Creation

1. Create a Greengrass group using your AWS account.
2. Sign-in to the AWS Management Console on your computer and open the AWS IoT console., Choose Get started, if this is the first attempt to open this console
    - In the navigation pane, choose Greengrass.

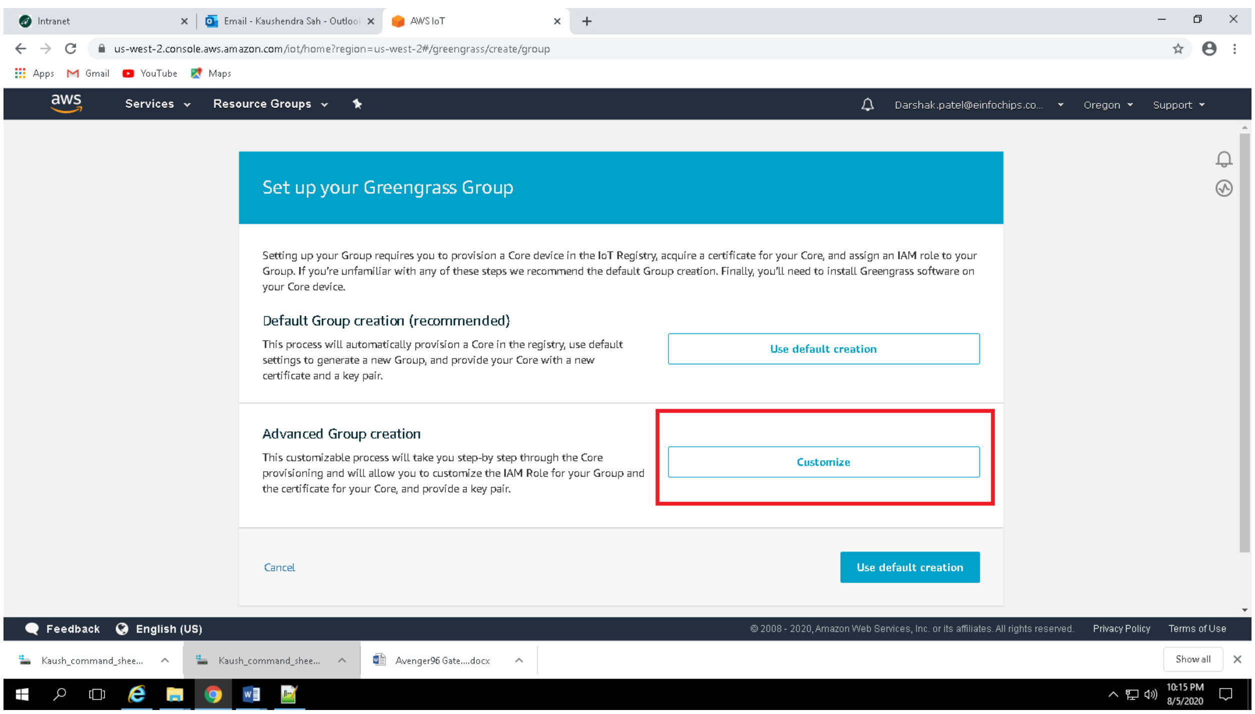


[Note: If you don't see the Greengrass node, change to an AWS Region that supports AWS IoT Greengrass. For the list of supported regions, see [AWS IoT Greengrass] in the Amazon Web Services General Reference.]

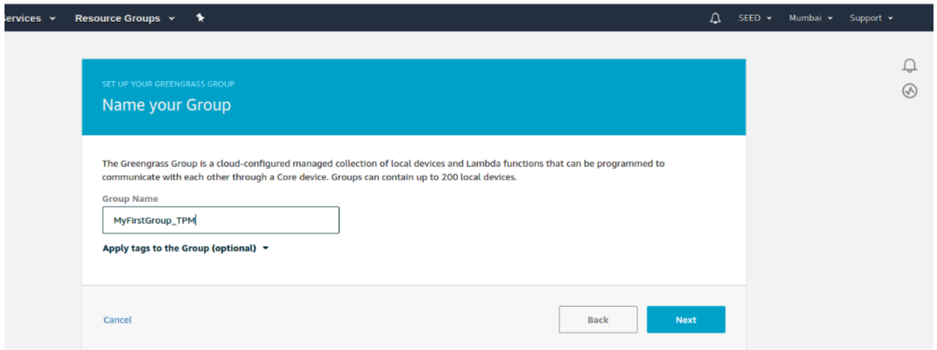
3. On the Welcome to AWS IoT Greengrass page, choose <Create a Group>.
    - Greengrass will need your permission to access other services. If prompted with this dialog box, choose 'Grant permission' to allow the console to create or configure the Greengrass service role for you.



4. On the Set up your Greengrass group page, choose "Customize" to create a group in AWS IoT Greengrass

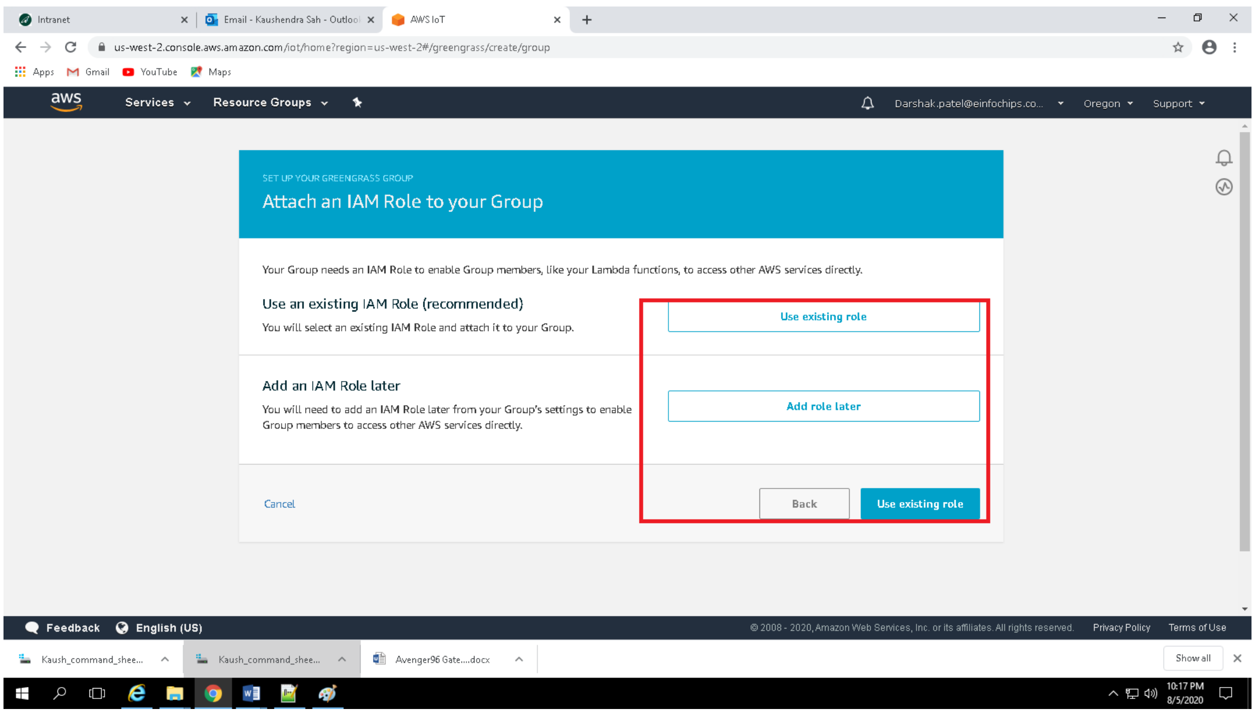


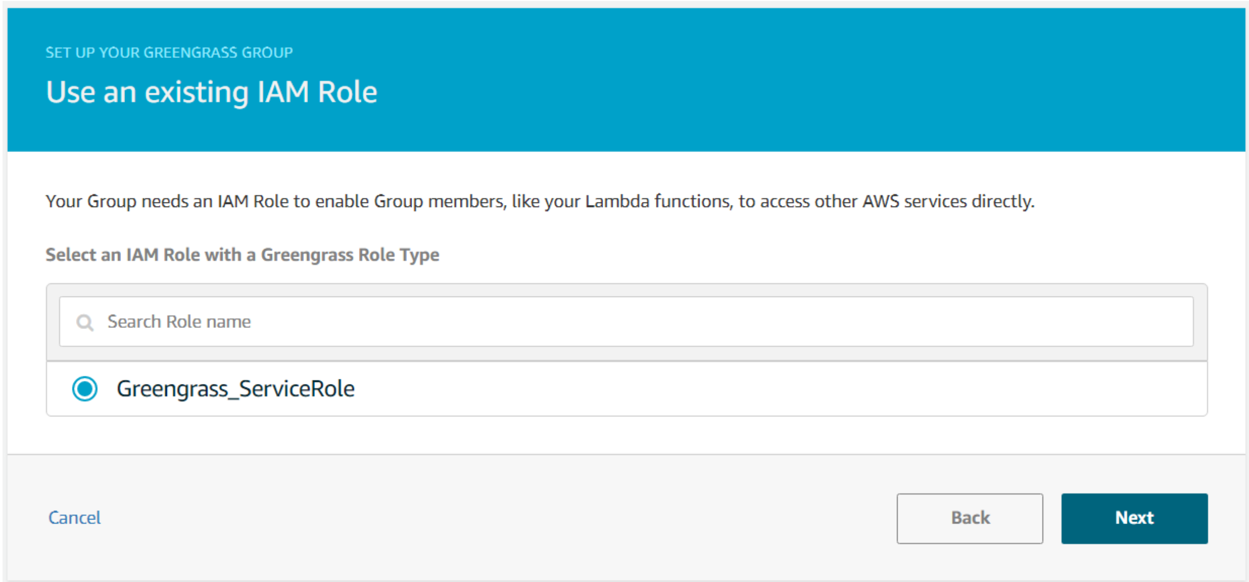
5. Enter a name for your group (for example, MyFirstGroup_TPM), and then choose Next



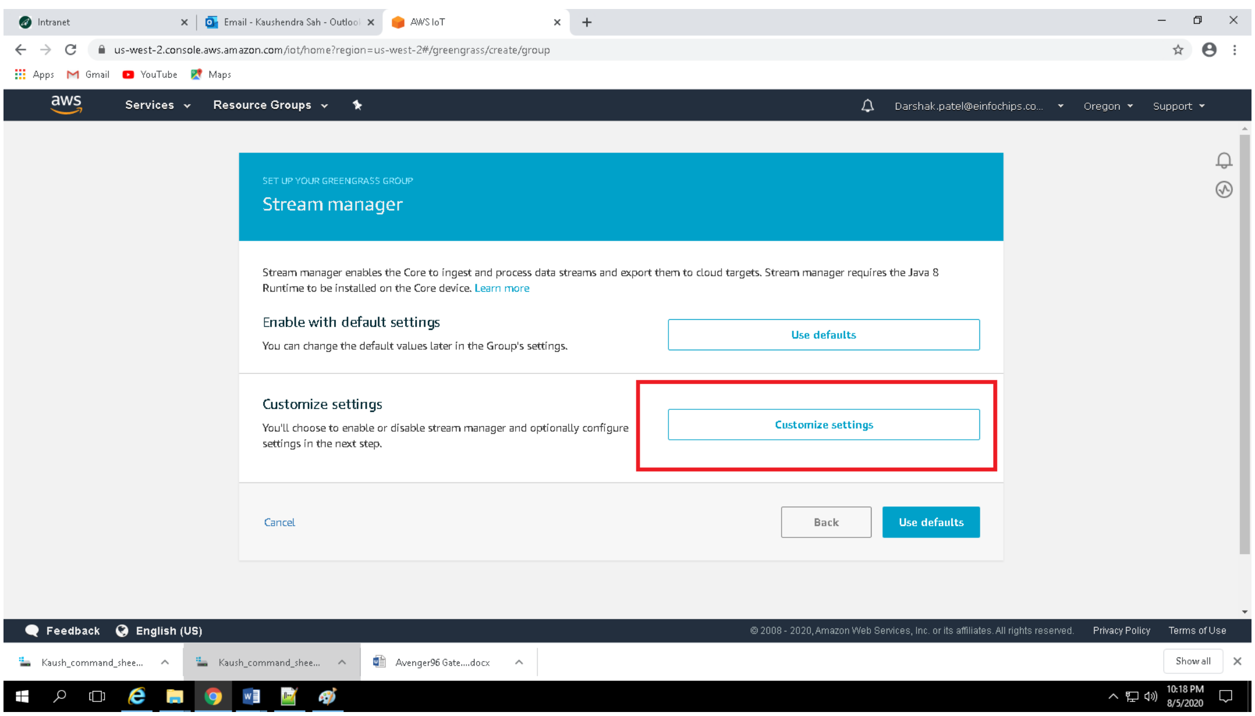
6. Add IAM Role to the Greengrass Group

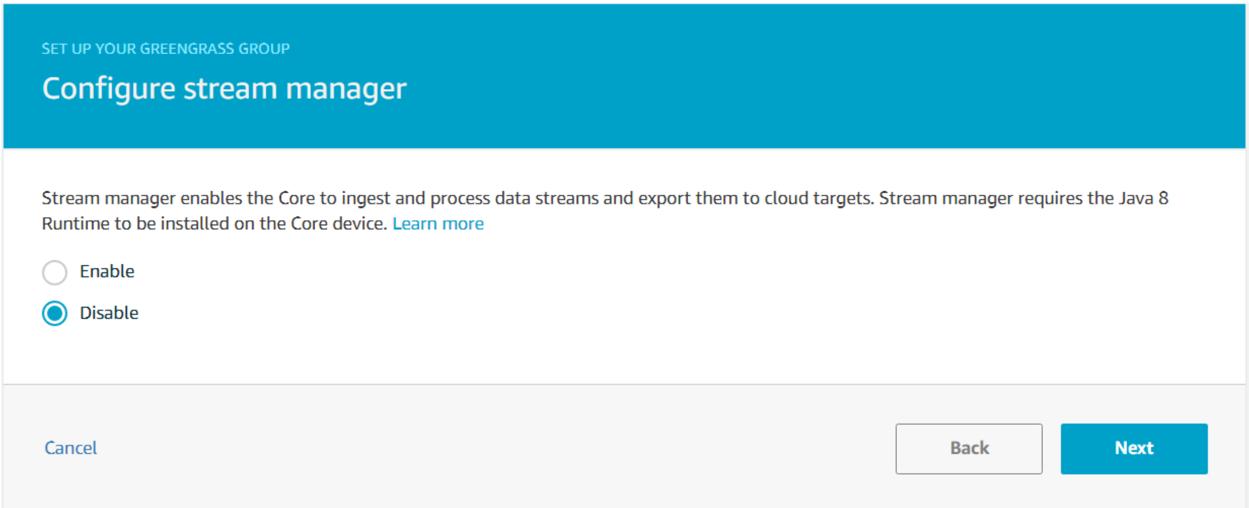
Click on “Use existing role” and select the Greengrass_ServiceRole.



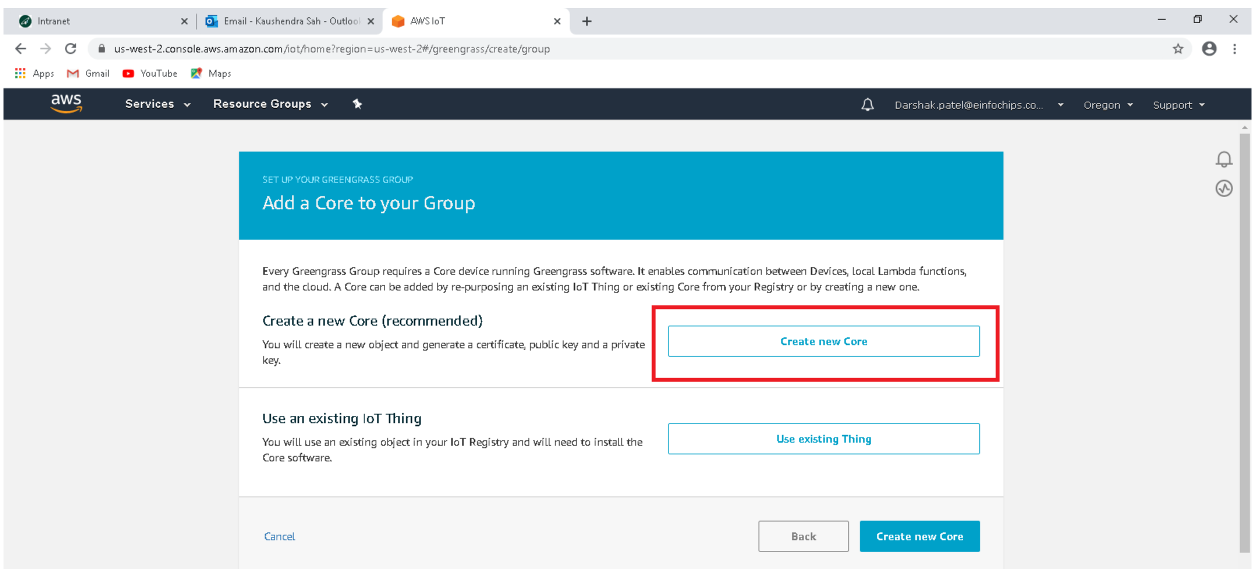


7. Select the Stream Manager option as **Customize** to Disable it

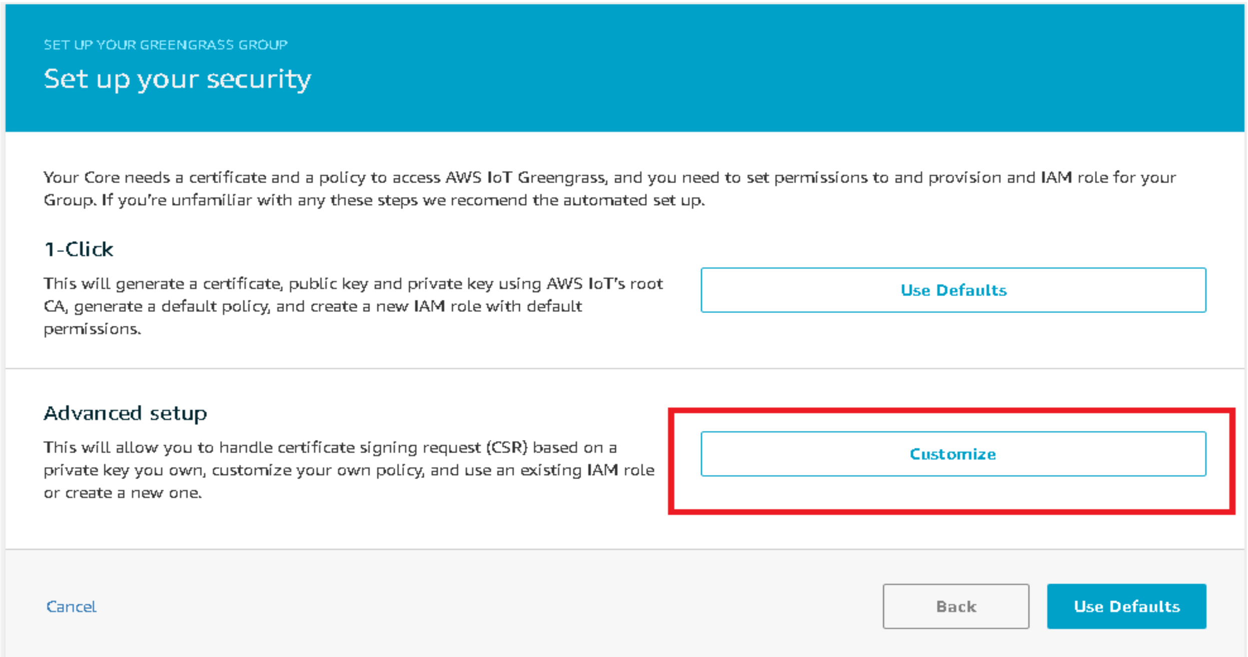




8. Select the Greengrass Core as per the Gateway Device running with it MyFirstGroup_TPM_Core



9. Select Security type as customize to upload the Gateway Device certificate Generated by OPTIGA™ TPM2.0 and signed with Registered RootCA with AWS as depicted in Section 4.4.1



4.6 AWS Console and Board: Setup AWS IoT for the Demo

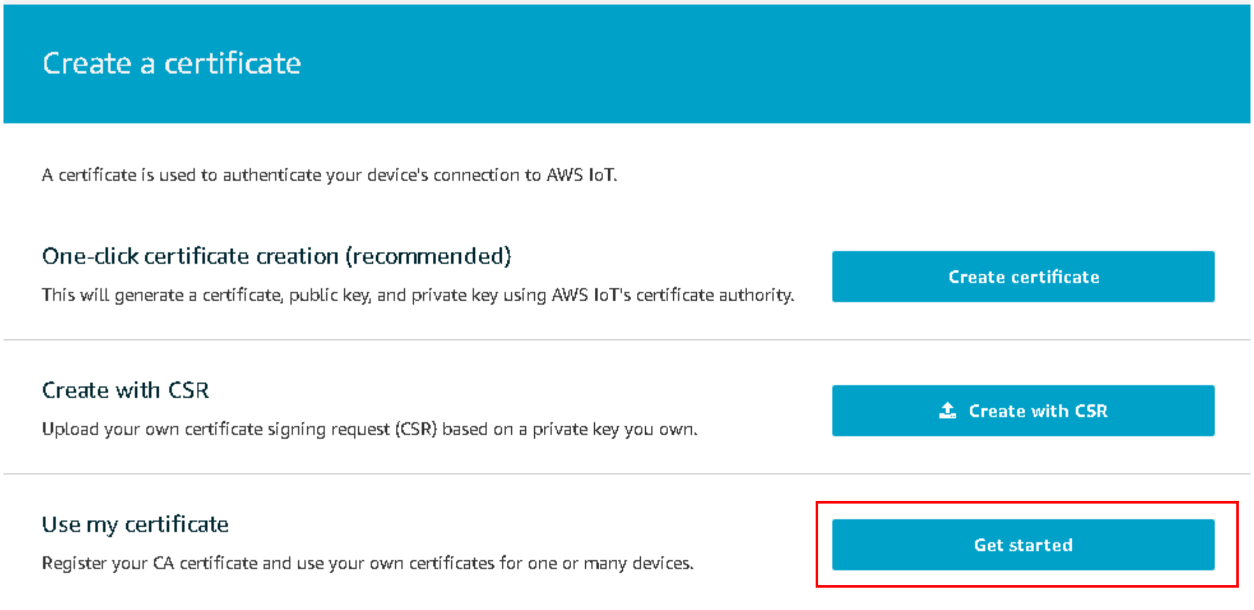
The user must go through the following steps to set and test the TLS connectivity with AWS IoT

1. Create an Amazon AWS account
2. Sign-in to the AWS IoT Console
3. Create (Register) a "thing" in the Thing Registry
4. Register the CA to the AWS IoT.

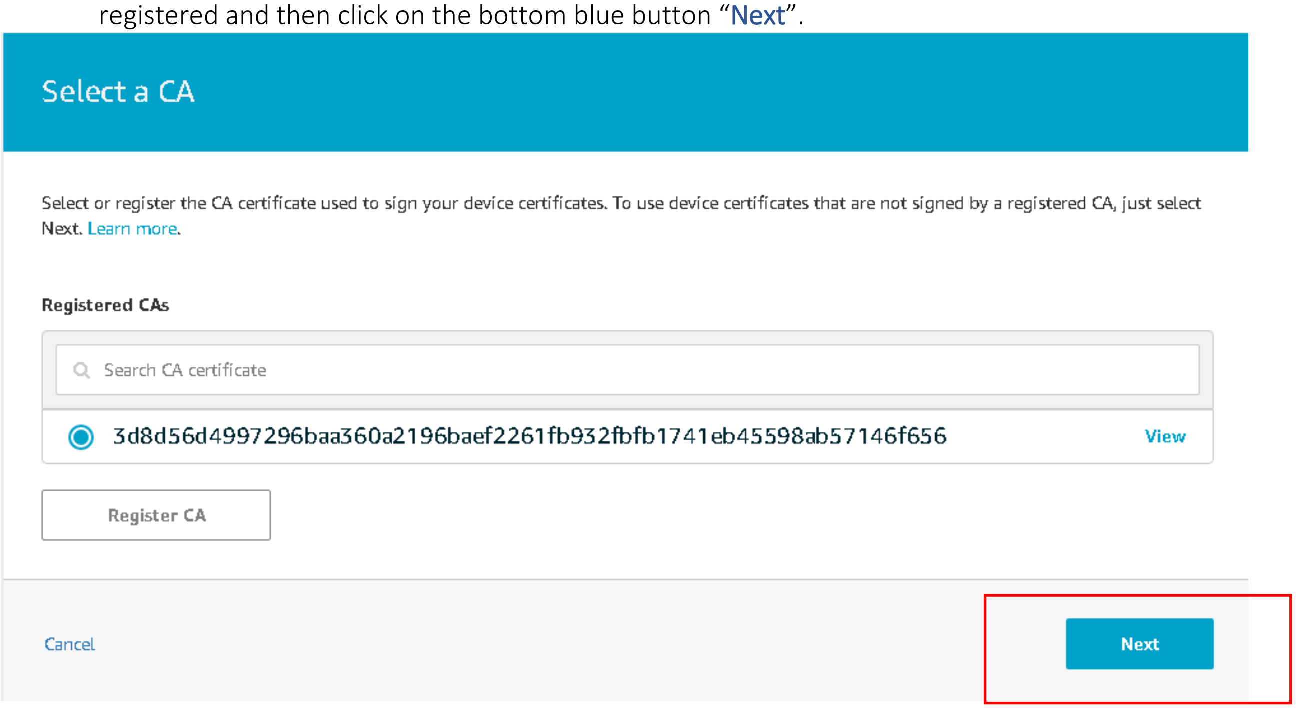
4.6.1 Register the Device Certificate to the AWS IoT for the "thing"

On the AWS console, after the AWS Custom CA Certificate has been registered and activated, for the "thing" that has been created, the user must click again on Security as shown in the screenshot below.

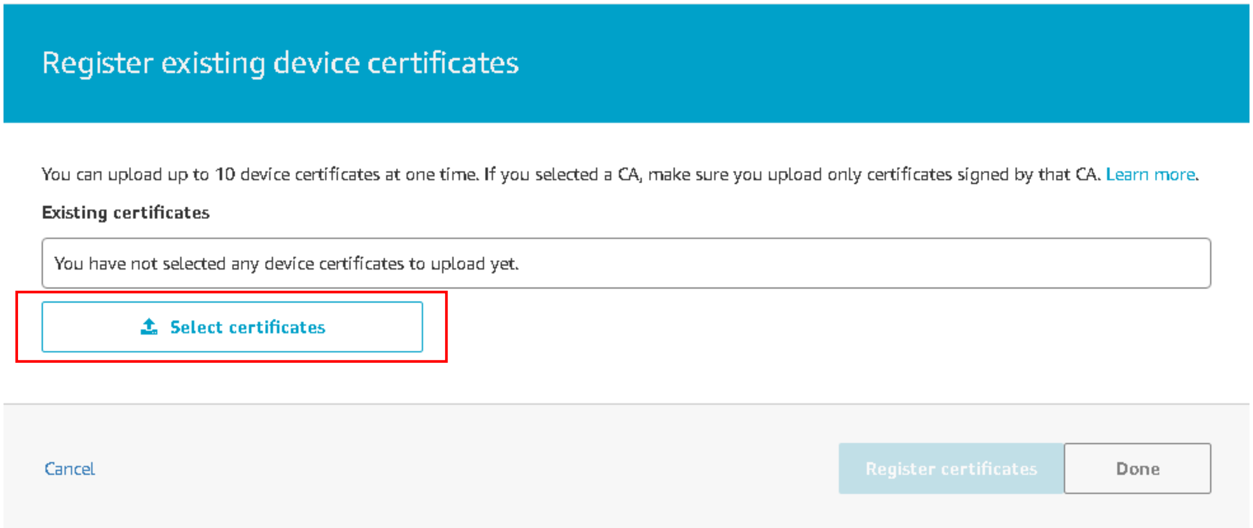
1. Then click on "View other options" and then "Use my certificate" (click on "Get started").



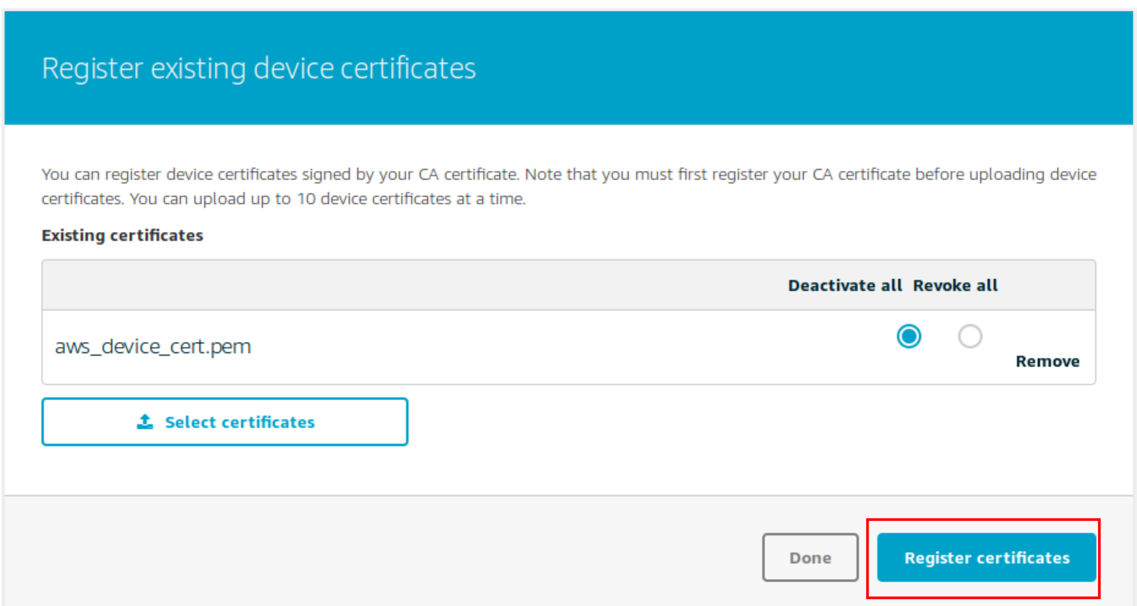
2. As shown in the screenshot below, the user will have to click and select the CA that was last registered and then click on the bottom blue button "Next".



3. As per the screenshot below the user has now the option to select to upload and register the Device Certificate.



4. Select the AWS Device Certificate, aws_device_cert.pem generated in section 4.4.2. Upload it to the AWS IoT "thing", and press the Register certificate blue button (check the "Activate all" radio button)



5. At this stage, the AWS IoT cloud has a "thing" ready to allow a device to connect to it: the device is registered with an active certificate.

4.6.2 AWS Console Create Publish/Subscribe Policy

For this example, device needs to be attached to a policy that allows them to subscribe and publish. To accomplish this:

1. Create a policy that allows subscription and publishing to a topic such as shown in the example policy below:

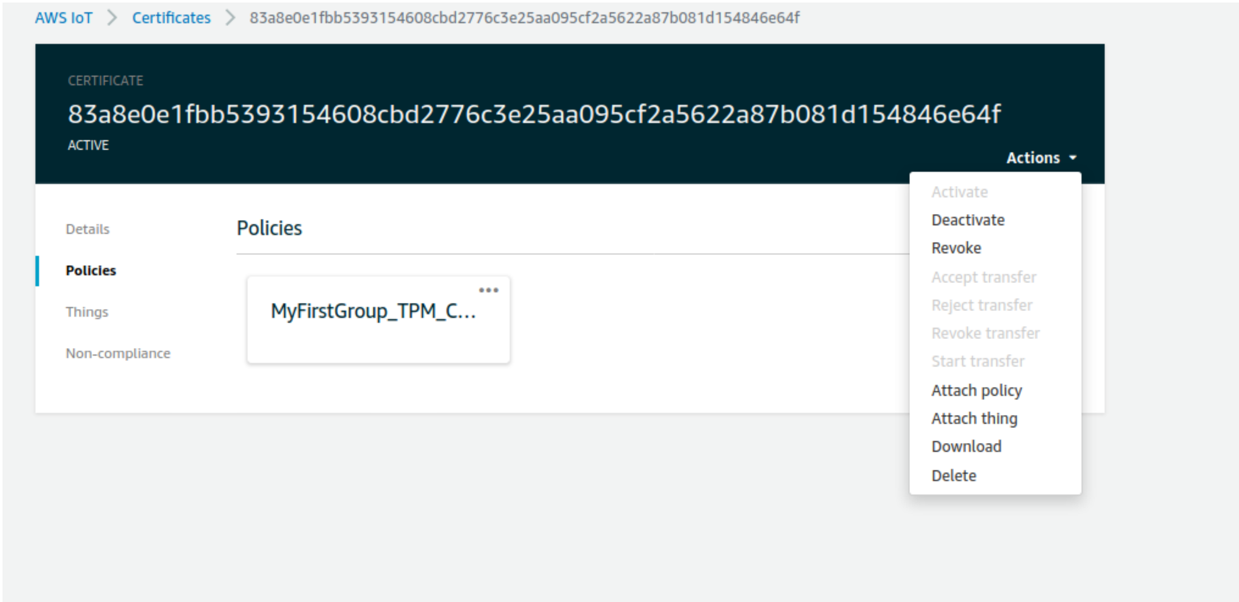
Policy document

The policy document defines the privileges of the request. **Learn more**

Version 1 **Edit policy document**

```
{
  "Version": "2012-10-17",
  "Statement": [
    {
      "Effect": "Allow",
      "Action": [
        "iot:Publish",
        "iot:Subscribe",
        "iot:Connect",
        "iot:Receive"
      ],
      "Resource": [
        "*"
      ]
    },
    {
      "Effect": "Allow",
      "Action": [
        "iot:GetThingShadow",
        "iot:UpdateThingShadow",
        "iot:DeleteThingShadow"
      ],
      "Resource": [
        "*"
      ]
    },
    {
      "Effect": "Allow",
      "Action": [
        "greengrass:*"
      ],
      "Resource": [
        "*"
      ]
    }
  ]
}
```

2. Attach the device certificate to the policy, e.g.



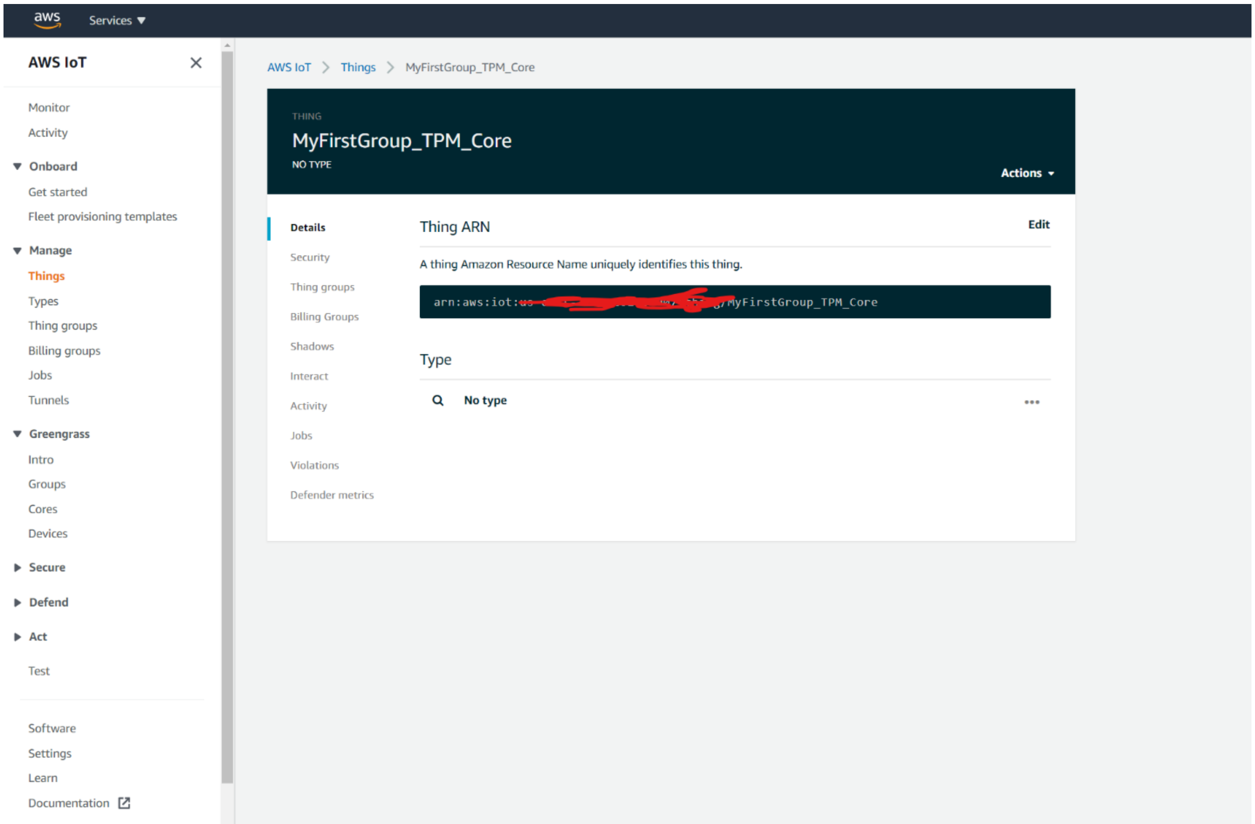
4.6.3 Linux Environment: Configure the AWS Example Application that Connects to AWS

To enable and use the OPTIGA™ TPM2.0 as Hardware Security Integration for Gateway (Device Demo) with AWS

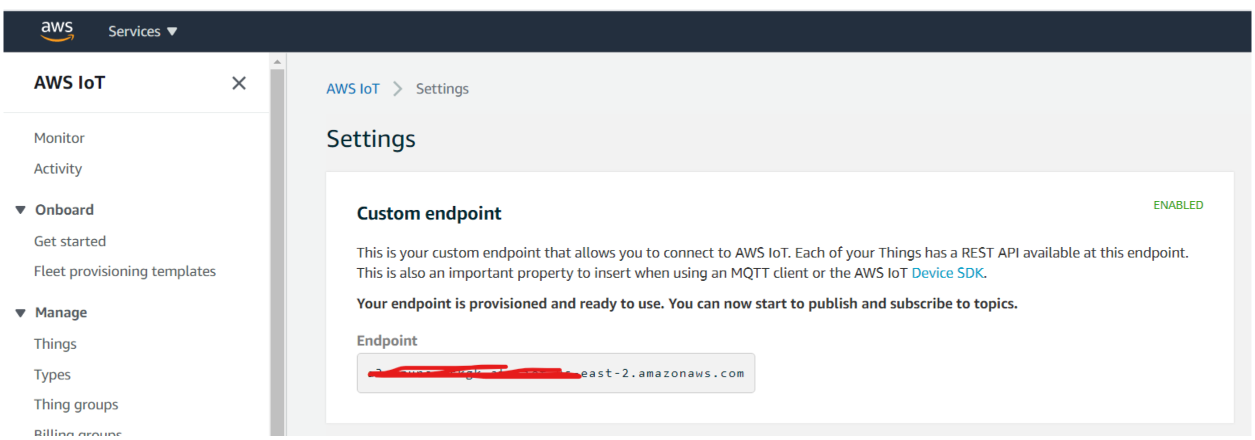
1. Please ensure all certificate and keys generated from section 4.4.1 and 4.4.2 are placed inside /greengrass/certs/
2. Enable it in the AWS IoT Greengrass config. Edit /greengrass/config/config.json and replace the configuration with the content based on your OpenSSL configuration and location of the keys. A complete example of the AWS IoT Greengrass configuration with the setup completed as described in the preceding sections resembles the following:

```
root@imx8qxpaiml:~# vi /greengrass/config/config.json
{
  "coreThing" : {
   "thingArn" :"arn:aws:iot:<AWS_REGION>:<AWS_ACCOUNT_NUMBER>:thing/<GG_Thing_Name>",
    "iotHost" : "XXXXXXXXXXXXXX-ats.iot.us-east-1.amazonaws.com",
    "ggHost" : "greengrass-ats.iot.ap-south-1.amazonaws.com",
    "keepAlive" : 600
  },
  "runtime" : {
    "cgroup" : {
      "useSystemd" : "yes"
    }
  },
  "managedRespawn" : false,
  "crypto" : {
    "PKCS11": {
        "OpenSSLEngine": "/usr/lib/engines/pkcs11.so",
        "P11Provider": "/usr/lib/pkcs11/libtpm2_pkcs11.so",
        "SlotLabel": "greengrass",
        "SlotUserPin": "1234"
    },
    "principals" : {
      "IoTCertificate" : {
        "privateKeyPath" :
"pkcs11:model=SLB9670;manufacturer=Infineon;token=greengrass;object=greenkey;type=private;pin-value=1234",
        "certificatePath" : "file:///greengrass/certs/aws_device_cert.pem"
      }
    },
    "caPath" : "file:///greengrass/certs/root.ca.pem"
  }
}
```

One can find ARN by navigating to the created thing in AWS IoT -> Manage -> Things ->Select thing and copy the thing ARN in the Details tab as shown below



One can find endpoint by navigating to AWS IoT -> Settings



4.6.4 Lambda Functions on AWS IoT Greengrass

This section will describe, how to create and deploy a Lambda function that sends MQTT messages from your AWS IoT Greengrass core device. The module describes Lambda function configurations, subscriptions used to allow MQTT messaging, and deployments to a core device

Create and Package a Lambda Function

In this step, you will:

- Download the AWS IoT Greengrass Core SDK for Python to your computer (and not AWS IoT Greengrass core device) from https://github.com/aws/aws-greengrass-core-sdk-python/
- Create a Lambda function deployment package that contains the function code and dependencies.
- Use the Lambda console to create a Lambda function and upload the deployment package.
- Publish a version of the Lambda function and create an alias that points to the version.

1. Downloaded the AWS IoT Greengrass Core SDK for Python to your computer.

```
Linux-PC $ git clone https://github.com/aws/aws-greengrass-core-sdk-python.git
Linux-PC $ cd aws-greengrass-core-sdk-python/
```

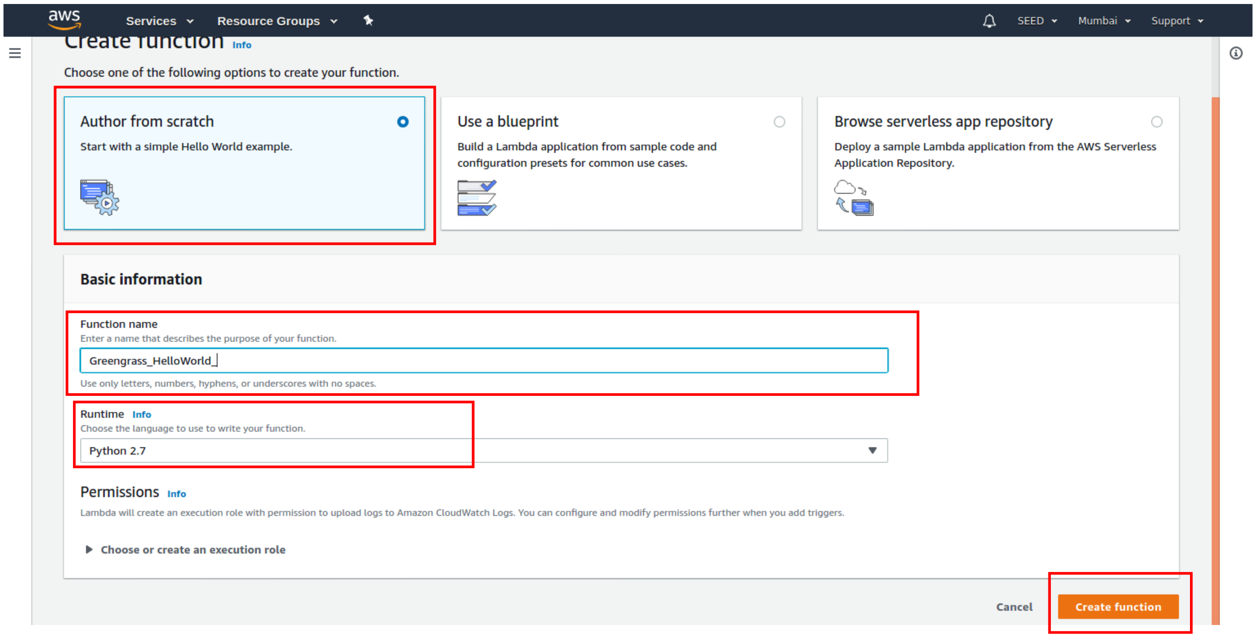
2. The Lambda function in this module uses:
   - The greengrassHelloWorld.py file in examples/HelloWorld. This is your Lambda function code. Every five seconds, the function publishes one of two possible messages to the hello/world topic.
   - The greengrasssdk folder. This is the SDK.
3. Copy the Greengrass SDK folder into the HelloWorld folder that contains greengrassHelloWorld.py.

```
Linux-PC $ cp -r greengrasssdk/ examples/HelloWorld/
```

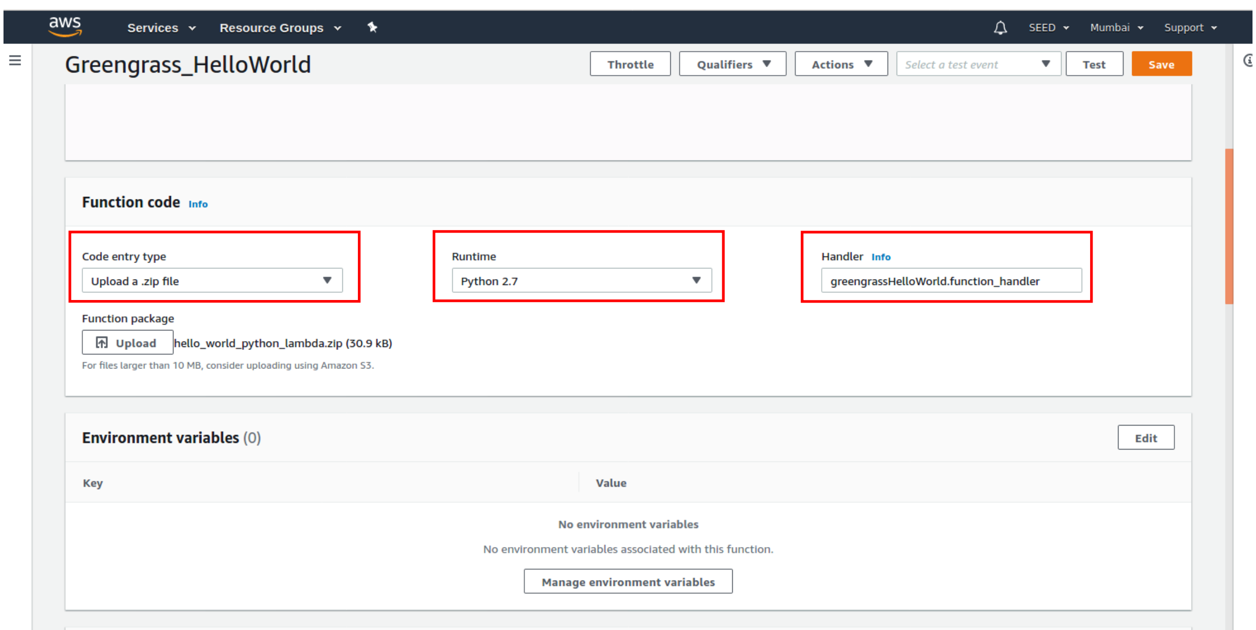
4. To create the Lambda function deployment package, save greengrassHelloWorld.py and the Greengrass SDK folder to a compressed zip file named hello_world_python_lambda.zip. The python file and Greengrass SDK folder must be in the root of the directory.


```
Linux-PC $cd examples/HelloWorld/
Linux-PC $ zip -r hello_world_python_lambda.zip greengrasssdk greengrassHelloWorld.py
```

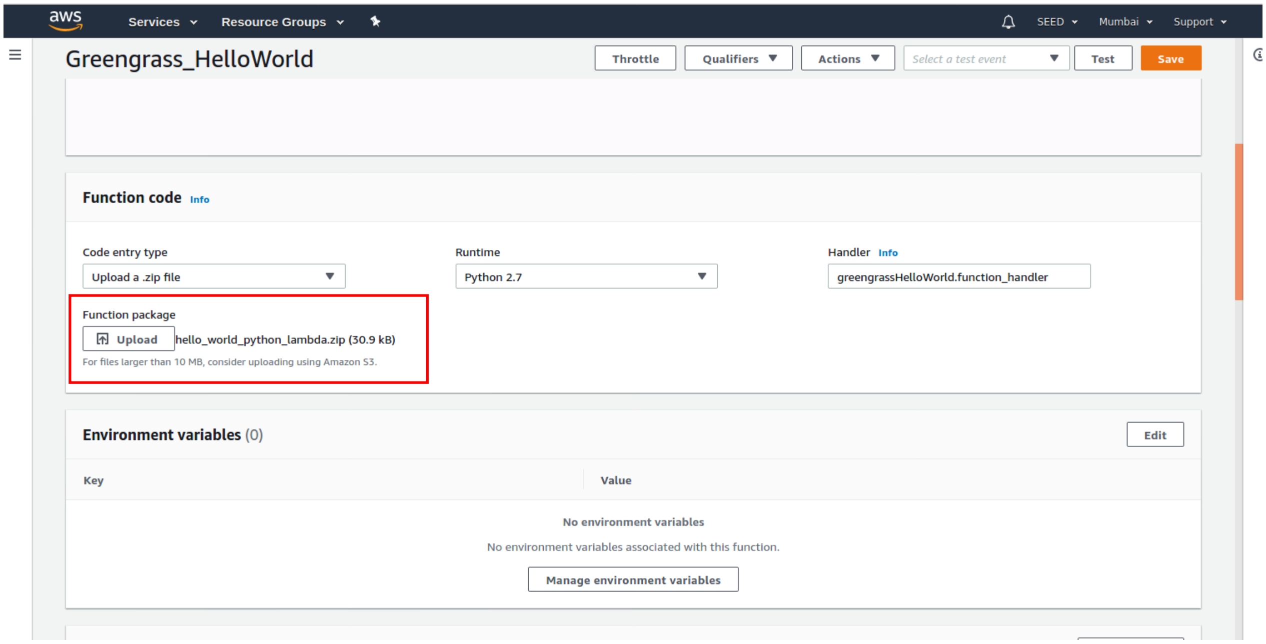
- Open the Lambda console and choose Create function
- Choose Author from scratch
- Name your function Greengrass_HelloWorld, and set the remaining fields as follows:
- For Runtime, choose Python 2.7
- Click on Create function at bottom.



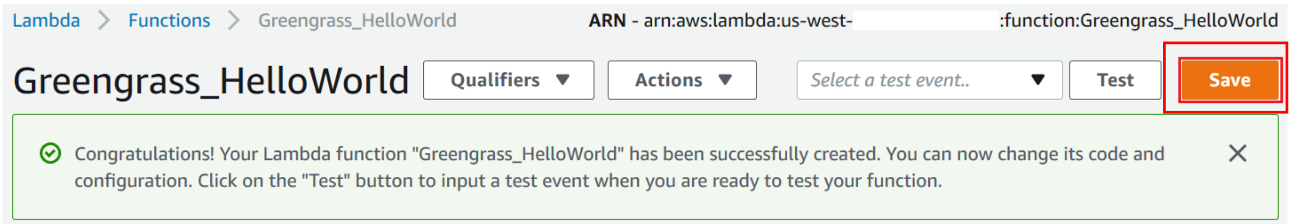
5. Upload your Lambda function deployment package:
   On the Configuration tab, under Function code, set the following fields:
   - For Code entry type, choose Upload a .zip file.
   - For Runtime, choose Python 2.7.
   - For Handler, enter greengrassHelloWorld.function_handler



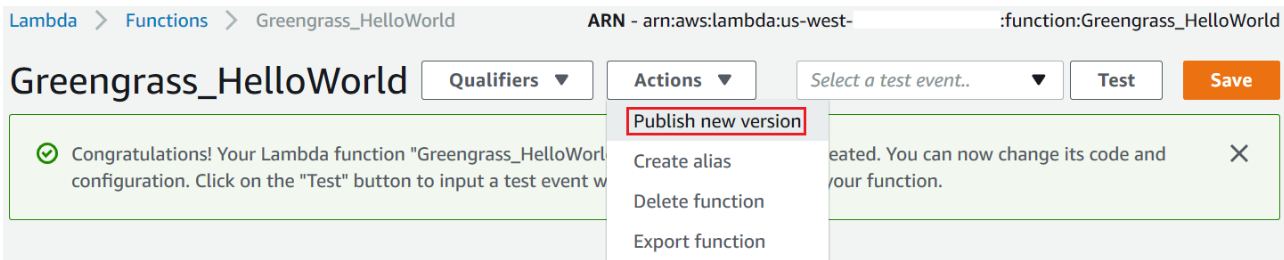
1. Choose Upload, and then choose hello_world_python_lambda.zip. (The size of your hello_world_python_lambda.zip file might be different from what is shown here.)


aws
Services
Resource Groups
SEED
Mumbai
Support
Greengrass_HelloWorld
Throttle
Qualifiers
Actions
Select a test event
Test
Save
Function code Info
Code entry type
Upload a .zip file
Runtime
Python 2.7
Handler Info
greengrassHelloWorld.function_handler
Function package
Upload
hello_world_python_lambda.zip (30.9 kB)
For files larger than 10 MB, consider uploading using Amazon S3.
Environment variables (0)
Edit
Key
Value
No environment variables
No environment variables associated with this function.
Manage environment variables

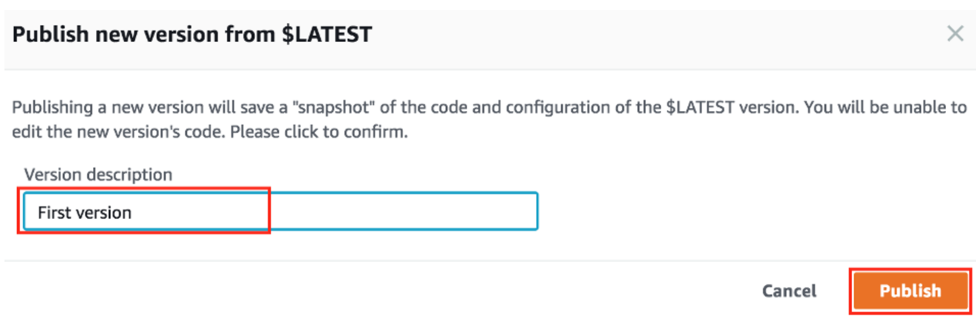
2. Choose Save



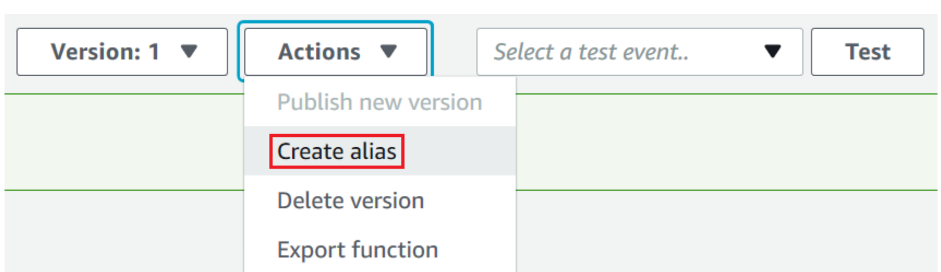
3. Publish the Lambda function:
    - From Actions, choose Publish new version.



4. For Version description, enter First version, and then choose Publish.

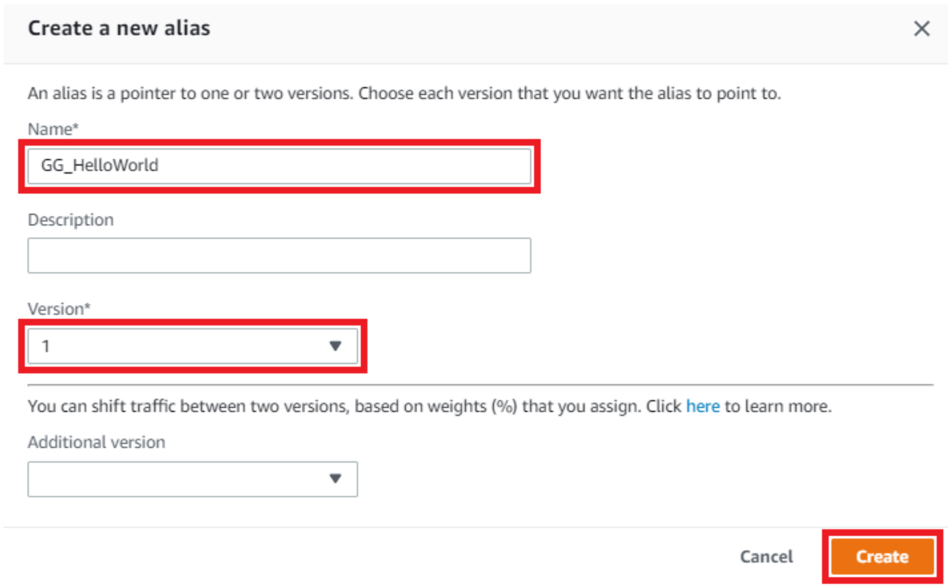


5. Create an alias for the Lambda function version:
    - From Actions, choose Create alias.



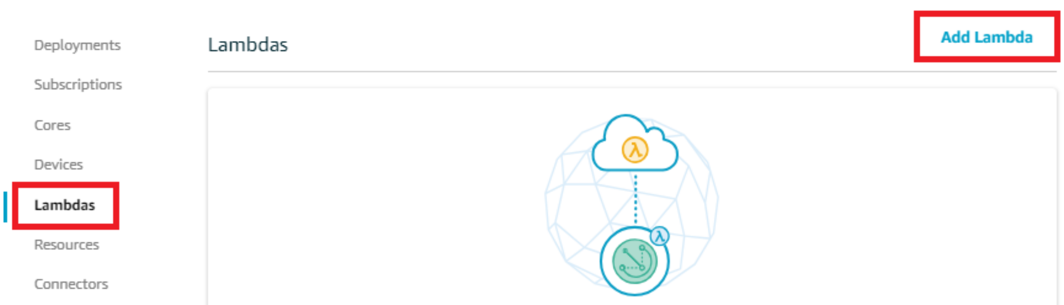
    - Name the alias GG_HelloWorld, set the version to 1 (which corresponds to the version that you just published), and then choose Create.

- Note: AWS IoT Greengrass does not support Lambda aliases for $LATEST versions.

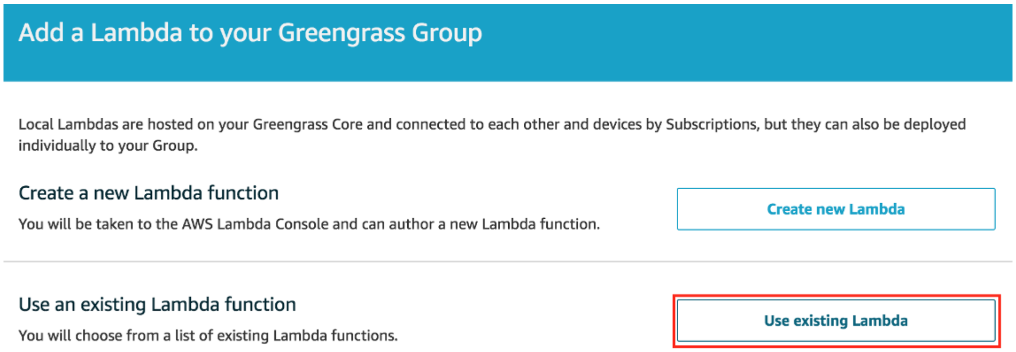


6. In the AWS IoT console, under Greengrass, choose Groups, and then choose the group that was created using the steps as mentioned above.

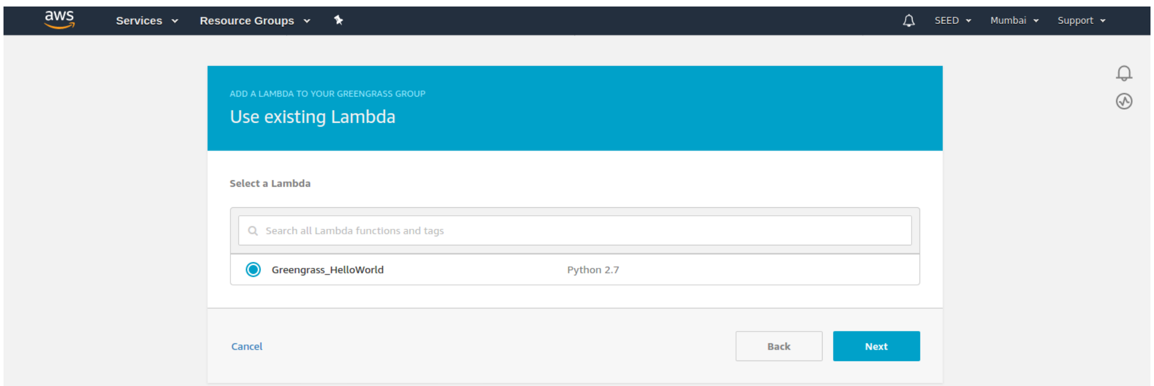
    - On the group configuration page, choose Lambdas, and then choose Add Lambda.



    - Choose Use existing Lambda.

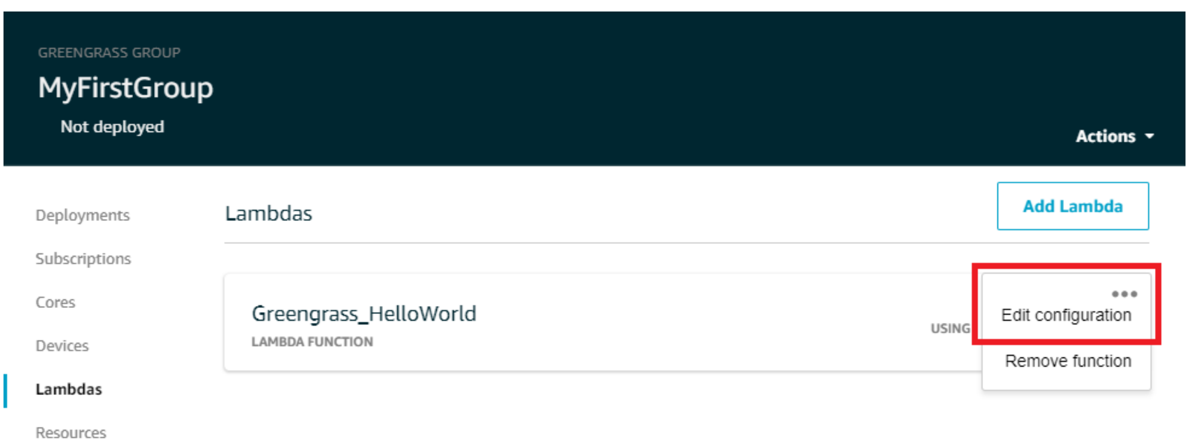


- Search for the name of the Lambda you created in the previous step (Greengrass_HelloWorld, not the alias name), select it, and then choose Next:



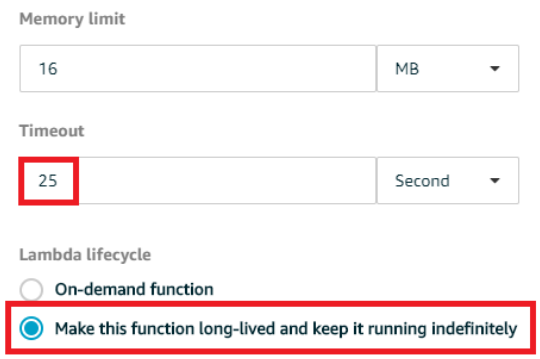
- For the version, choose Alias: GG_HelloWorld, and then choose Finish. You should see the Greengrass_HelloWorld Lambda function in your group, using the GG_HelloWorld alias.

- Choose the ellipsis (...), and then choose Edit Configuration:

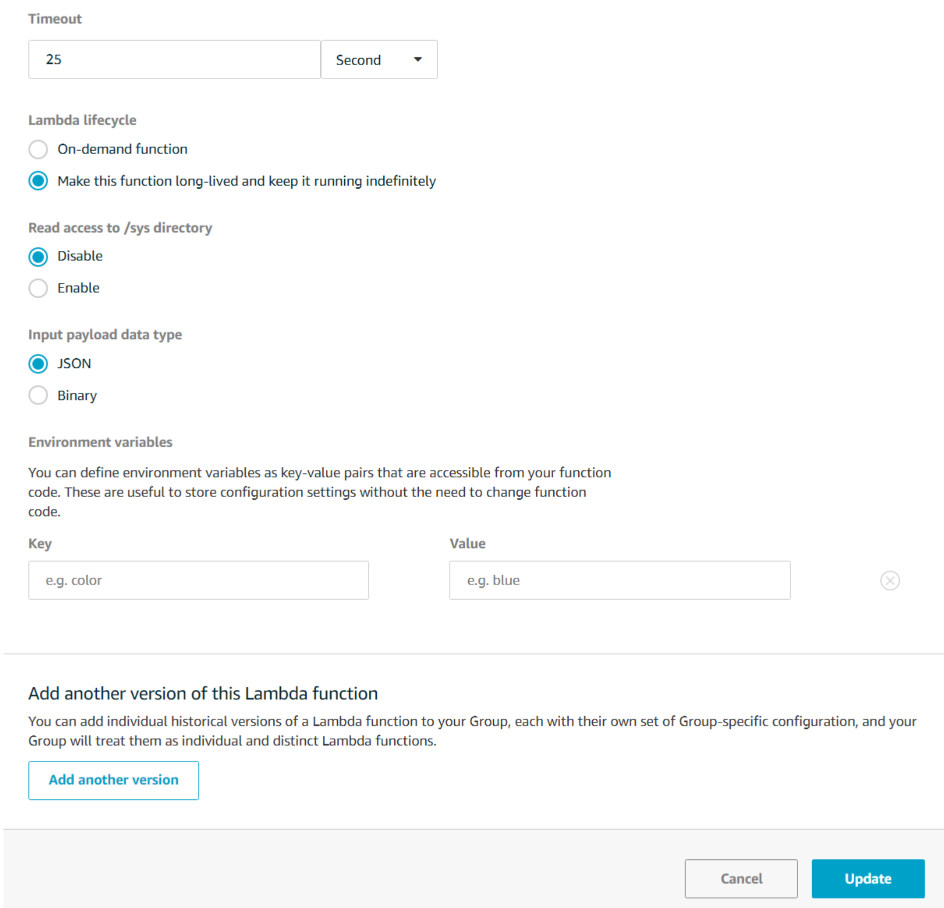


7. On the Group-specific Lambda configuration page, edit the following:

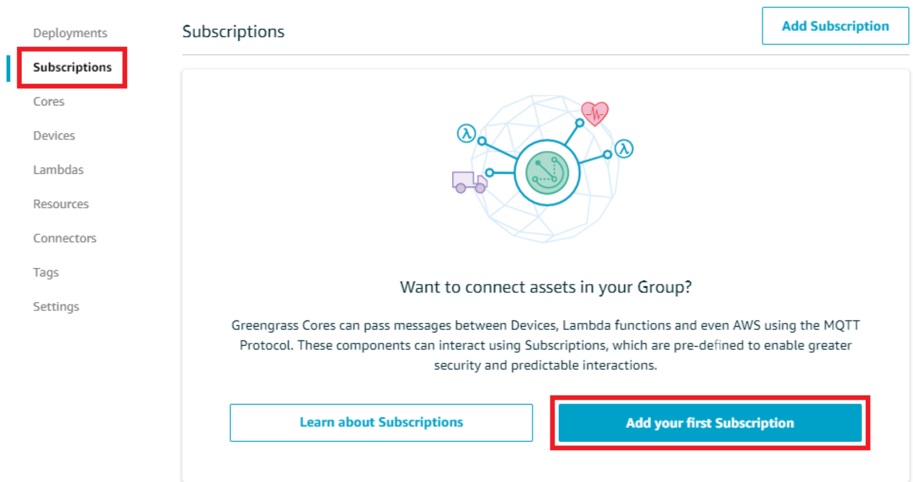
- Set Timeout to 25 seconds. This Lambda function sleeps for 20 seconds before each invocation.
- For Lambda lifecycle, choose Make this function long-lived and keep it running indefinitely.



- Keep the default values for all other fields, such as Run as, Containerization, Input payload data type, and choose Update to save your changes.

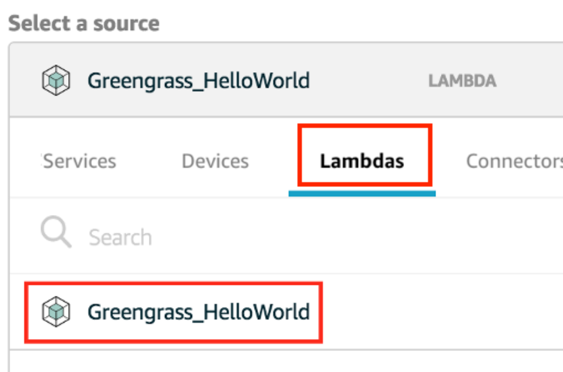


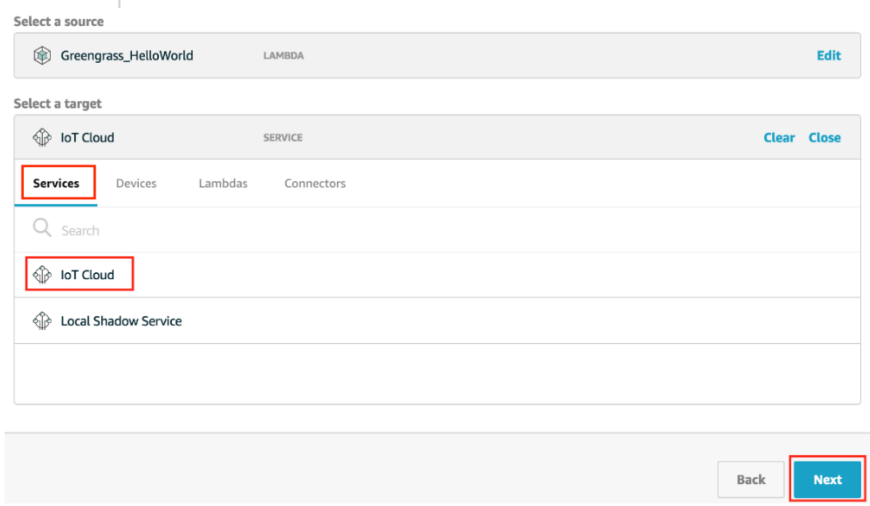
8. On the group configuration page, choose Subscriptions, and then choose Add your first Subscription.



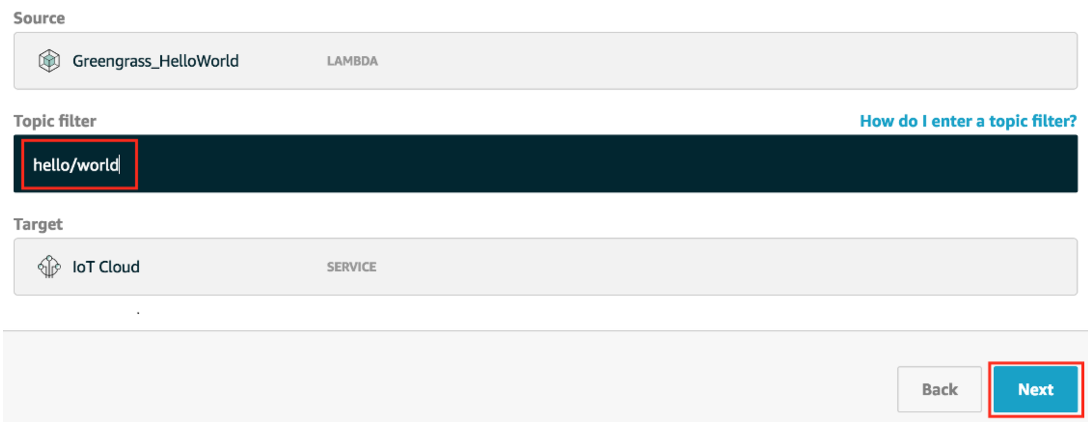
- In Select a source, choose Select. Then, on the Lambdas tab, choose Greengrass_HelloWorld as the source.

9. To Select a target, choose Select. Then, on the Service tab, choose IoT Cloud, and then choose next.

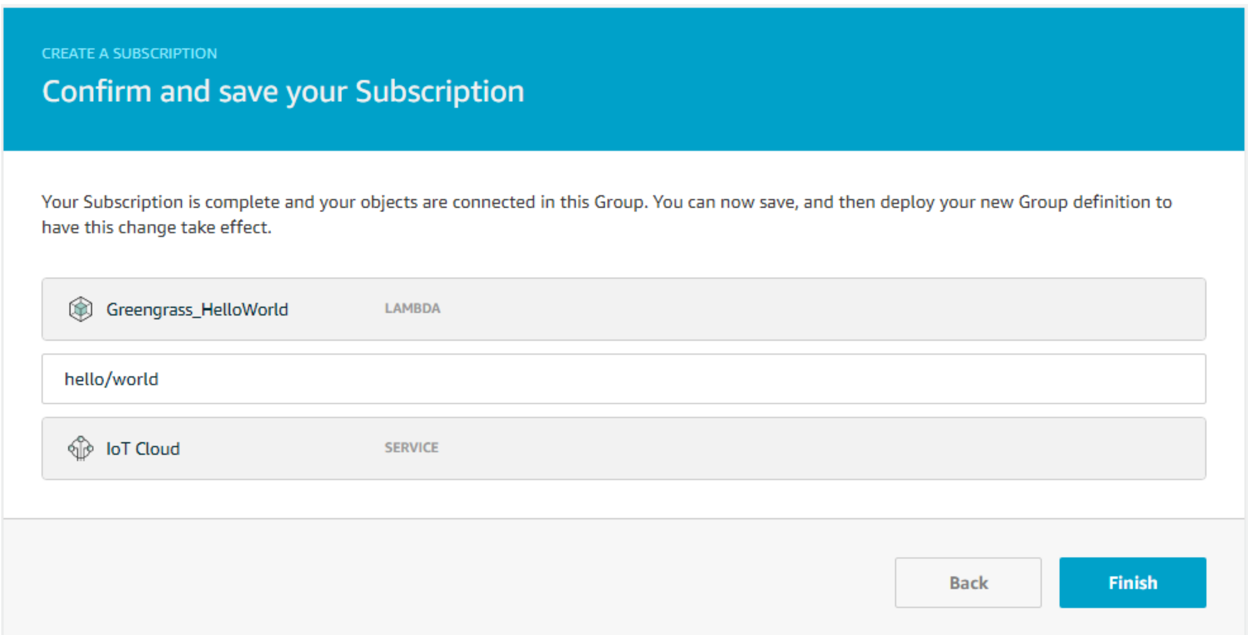




- For Topic filter, enter hello/world, and then choose Next.



- Click on Finish



10. Configure the group's logging settings. User can configure AWS IoT Greengrass system components and user-defined Lambda functions to write logs to the file system of the core device.
    - On the group configuration page, choose Settings.
    - For Local logs configuration, choose Edit.
    - On the Configure Group logging page, choose Add another log type.
    - For event source, choose User Lambdas and Greengrass system, and then choose Update.
    - Keep the default values for logging level and disk space limit, and then choose Save.
    - Disable the Stream Manager Status.

4.6.5 On Board: Execute the AWS Example Application

To check whether the daemon is running:

```
root@imx8qxpaiml:~# ps aux | grep -E 'Greengrass.*daemon'
```

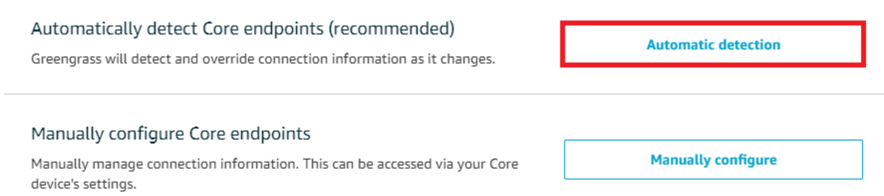
If the output contains a root entry for /Greengrass/ggc/packages/1.10.0/bin/daemon, then the daemon is running.

1. To start the daemon:

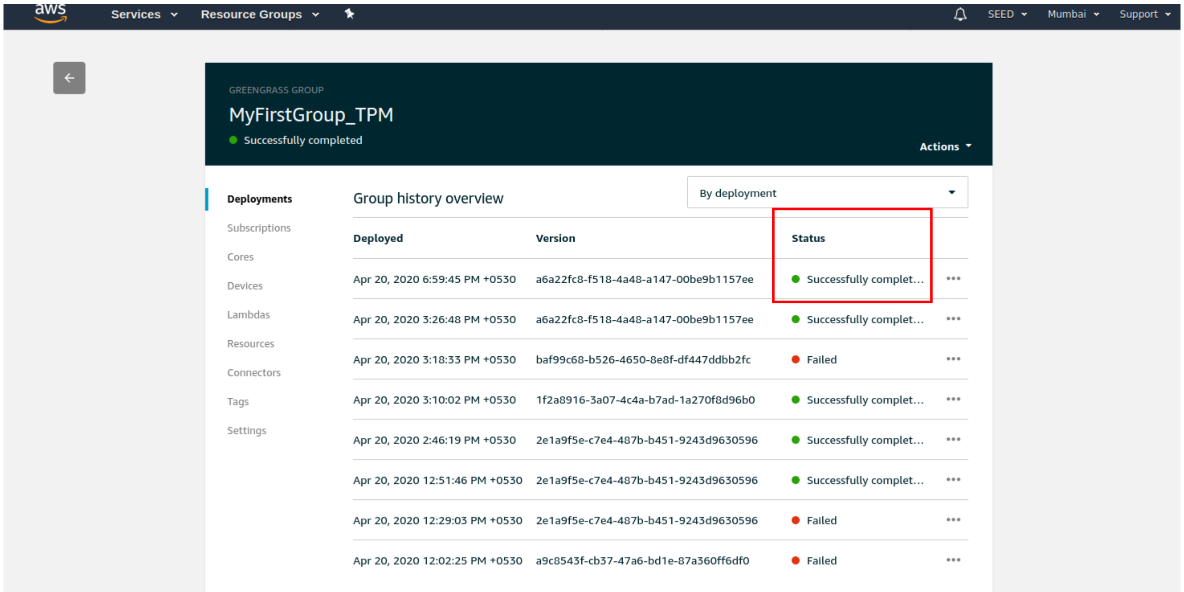
```
root@imx8qxpaiml:~# cd /greengrass/ggc/core/
root@imx8qxpaiml:~# ./greengrassd start
```

2. In the AWS IoT console, on the group configuration page, from Actions, choose Deploy.

3. Choose Automatic detection to allow devices discover your core page. This enables devices to automatically acquire connectivity information for the core, such as IP address, DNS, and port number. Automatic detection is recommended, but AWS IoT Greengrass also supports manually specified endpoints. You are only prompted for the discovery method for the first time when the group is deployed.

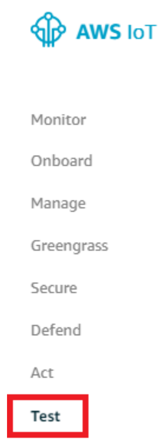


4. The first deployment might take a few minutes. When the deployment is complete, you should see successfully completed in the status column on the Deployments page:

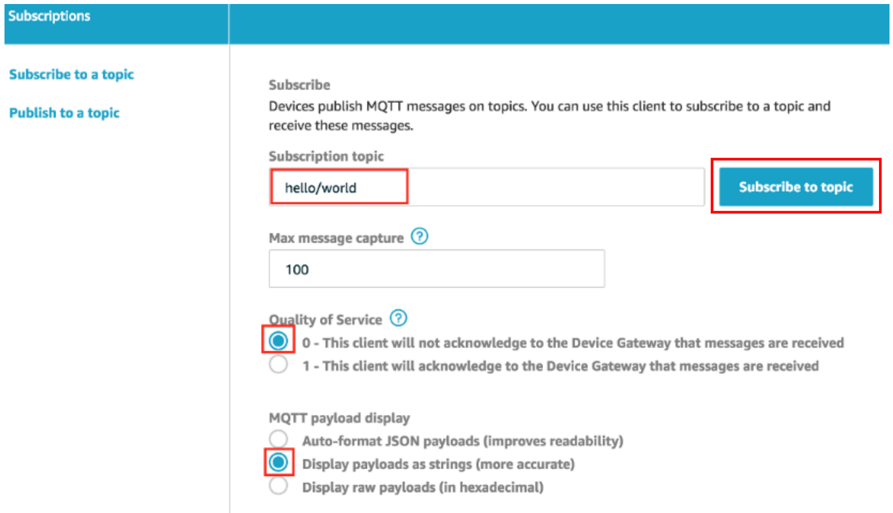


5. Verify that the Lambda Function Is Running on the Core Device with H/w Security enabled with OPTIGA™ TPM.0 security keys.

6. From the navigation pane of the AWS IoT console, choose Test.

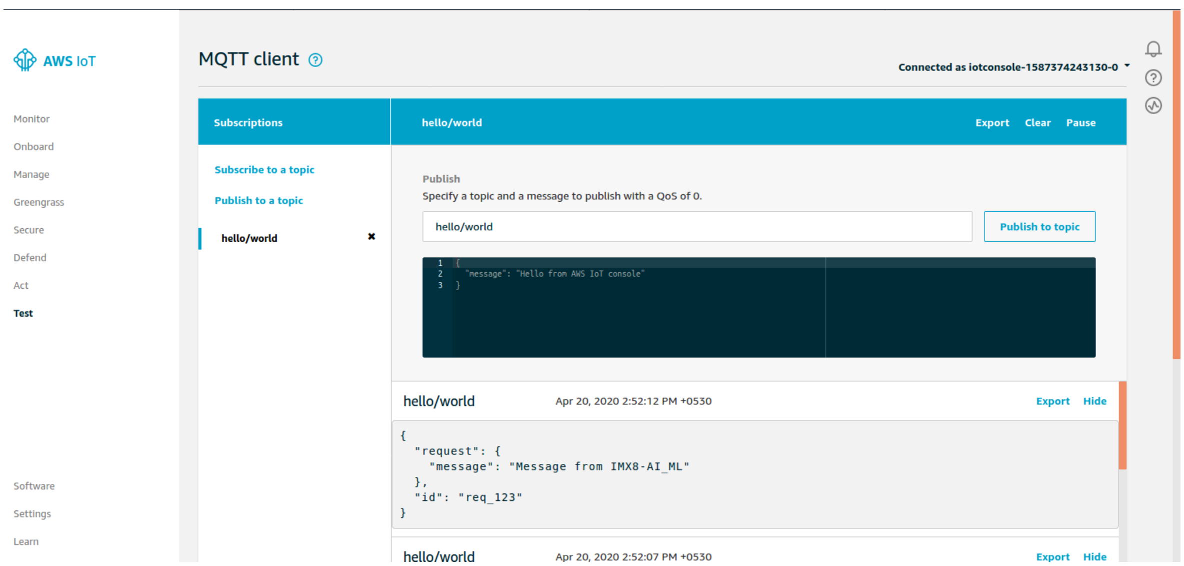


7. Choose Subscribe to topic, and configure the following fields:
   - For Subscription topic, enter hello/world. (Do not choose Subscribe to topic yet.)
   - For Quality of Service, choose 0.
   - For MQTT payload display, choose Display payloads as strings.
   - Click on "Choose Subscribe to topic"



[Note: Assuming the Lambda function is running on your device, it publishes messages similar to the hello/world topic]

8. Display MQTT messages on the screen like "Message from AI_ML"



5 IMX8X SECURE BOOT

5.1 Preparing the environment to build a secure boot image

Before continuing, ensure the following:

1. imx-mkimage downloaded and built with i.MX 8 container support.
2. Download the imx-mkimage tool

```
Linux-PC $ mkdir –p Secureboot_AIML
Linux-PC $ cd Secureboot_AIML
Linux-PC $ git clone https://source.codeaurora.org/external/imx/imx-mkimage/
Linux-PC $ cd imx-mkimage
Linux-PC $ git checkout origin/imx_4.9.88_imx8qxp_beta2
```

3. Download the scfw_tcm.bin from the SEED_Suit_AIML_Release_Package and copy to Secureboot_AIML

```
Linux-PC $ cp scfw_export_mx8qx/build_mx8qx/scfw_tcm.bin Secureboot_AIML/.
```

4. Copy ARM Trusted Firmware (ATF)

```
Linux-PC $cd Aiml /bld-xwayland-aiml/tmp/work/imx8qxpaiml-poky-linux/imx-
atf/1.5+gitAUTOINC+d6451cc1e1-r0/git/build/imx8qxp/release/

Linux-PC $ cp bl31.bin Secureboot_AIML/.
```

5. Copy AHAB Container Image

```
Linux-PC $ cd Aiml /bld-xwayland-aiml/tmp/deploy/images/imx8qxpaiml/
Linux-PC $ cp mx8qx-ahab-container.img Secureboot_AIML/.
Linux-PC $ cd Secureboot_AIML/.
Linux-PC $ mv mx8qx-ahab-container.img ahab-container.img
```

6. Preparing U-Boot to support AHAB secure boot features

- Add CONFIG_AHAB_BOOT=y in Aiml/bld-xwayland-aiml/tmp/work/imx8qxpaiml-poky-linux/u-boot-imx/2018.03-r0/git/configs/ imx8qxp_aiml_defconfig

- Build the U-boot now,

```
Linux-PC $ cd Aiml/
Linux-PC $EULA=1 MACHINE=imx8qxpaiml DISTRO=fsl-imx-xwayland source ./fsl-setup-release.sh-b bld-
xwayland-aiml/
Linux-PC $bitbake v u-boot-imx
```

7. Copy U-boot

```
Linux-PC $ cp tmp/deply/images/aiml/uboot.bin Secureboot_AIML/
```

8. Copy Kernel image

```
Linux-PC $ cp bld-xwayland-aiml/tmp/deploy/images/imx8qxpaiml/fsl-imx8qxp-aiml.dtb
Secureboot_AIML/fsl-imx8qxp-lpddr4-arm2.dtb

Linux-PC $ cp bld-xwayland-aiml/tmp/deploy/images/imx8qxpaiml/Image Secureboot_AIML/.
```

9. Copy CSF description file

```
Linux-PC $ cp bld-xwayland-aiml/work/imx8qxpaiml-poky-linux/csf_boot_image.txt Secureboot_AIML/
```

- Downloaded the Code Signing Tool, available on the NXP Website.

5.2 Building a Secure Signed Image

5.2.1 Programming SRK Hash

As described in introduction_ahab document the SRK Hash fuse values are generated by the srktool and should be programmed in the SoC SRK_HASH [511:0] Fuses.

The first step is to generate the private keys and public keys certificates. The AHAB architecture is based on a Public Key Infrastructure (PKI) tree.

The Code Signing Tools package contains an OpenSSL based key generation script under keys / directory. The ahab_pki_tree.sh script generates a PKI tree containing 4 Super Root Keys (SRK), to include a subordinate SGK key.

The AHAB supports both RSA and ECC keys. A new PKI tree can be generated by following the example below using CST Tool:

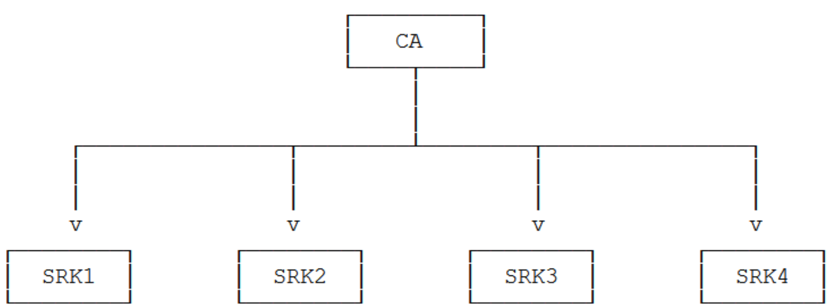
- Generating a P384 ECC PKI tree on CST v3.1.0:

```
Linux-PC $ cd Secureboot_AIML/release/keys
Linux-PC $ ./ahab_pki_tree.sh
...
Do you want to use an existing CA key (y/n)?: n
Do you want to use Elliptic Curve Cryptography (y/n)?: y
Enter length for elliptic curve to be used for PKI tree:
```

```
Possible values p256, p384, p521:  p384
Enter the digest algorithm to use: sha384
Enter PKI tree duration (years): 5
Do you want the SRK certificates to have the CA flag set? (y/n)?: n
```

```
Output:-
+++++++++++++++++++++++++++++++++++++++++
+ Generating SRK key and certificate 4 +
+++++++++++++++++++++++++++++++++++++++++

read EC key
writing EC key
Using configuration from ../ca/openssl.cnf
Check that the request matches the signature
Signature ok
The Subject's Distinguished Name is as follows
commonName           :ASN.1 12:'SRK4_sha384_secp384r1_v3_usr'
Certificate is to be certified until Aug 12 06:50:58 2025 GMT (1825 days)

Write out database with 1 new entries
Data Base Updated
```

The diagram below illustrate the PKI tree generated:



Note: Due to a limitation in i.MX8QXP B0 silicon it's not possible to use RSA 4096-bit SRK keys with an additional subordinate SGK key.

Generating a SRK Table and SRK Hash

The next step is to generate the SRK Table and its respective SRK Table Hash from the SRK public key certificates created in one of the steps above.

In the AHAB architecture, the SRK Table is included in the signed image and the SRK Hash is programmed in the SoC SRK_HASH[511:0] fuses.

On the target device during the authentication process the AHAB code verifies the SRK Table against the SoC SRK_HASH fuses. In case the verification is successful the root of trust is established, and the AHAB code can progress with the image authentication.

The srktool can be used for generating the SRK Table and its respective SRK Table Hash.

- Generating SRK Table and SRK Hash in Linux 64-bit machines:

```
Linux-PC $ cd ../crts/
Linux-PC $ ../linux64/bin/srktool-a-s sha384-t SRK_1_2_3_4_table.bin \
    -e SRK_1_2_3_4_fuse.bin-f 1-c \
     SRK1_sha384_secp384r1_v3_usr_crt.pem,\
     SRK2_sha384_secp384r1_v3_usr_crt.pem,\
     SRK3_sha384_secp384r1_v3_usr_crt.pem,\
     SRK4_sha384_secp384r1_v3_usr_crt.pem
```

- Optionally users can check if the sha512sum of SRK_1_2_3_4_table matches with the SRK_1_2_3_4_fuse.bin:

```
Linux-PC $ od-t x4--endian=big SRK_1_2_3_4_fuse.bin
0000000 4eaa9ae5 33332597 3f0883f7 b3bb107c
0000020 d1b2eb8f 0961f34b 23548195 af99657c
0000040 63c632ff 5d8c7b4c 297012bb 1dfe01d1
0000060 12af36be 1b2c4737 8cd5d67a e33d2521
0000100

Linux-PC $ sha512sum SRK_1_2_3_4_table.bin
4eaa9ae5333325973f0883f7b3bb107cd1b2eb8f0961f34b23548195af99657c63c632ff5d8c7b4c29701
2bb1dfe01d112af36be1b2c47378cd5d67ae33d2521  SRK_1_2_3_4_table.bin
imx8@VM143:crts$
```

5.2.2 Prepare the boot image layout

- Copy following binary from Secureboot_AIML/ to imx-mkimage/iMX8QX/

```
Linux-PC $ cd Secureboot_AIML/
Linux-PC $ cp u-boot.bin imx-mkimage/iMX8QX/
Linux-PC $ cp scfw_tcm.bin imx-mkimage/iMX8QX/
Linux-PC $ cp bl31.bin imx-mkimage/iMX8QX/
Linux-PC $ cp ahab-container.img imx-mkimage/iMX8QX/
Linux-PC $ cp fsl-imx8qxp-lpddr4-arm2.dtb  imx-mkimage/iMX8QX/
```

- To generate the flash.bin file (On i.MX 8 QXP)

```
Linux-PC $ cd Secureboot_AIML/imx-mkimage
```

```
Linux-PC $ make SOC=iMX8QX flash
```

```
output:
root@VM147:imx-mkimage# make SOC=iMX8QX flash
./../mkimage_imx8-commit > head.hash
642+1 records in
642+1 records out
657752 bytes (658 kB, 642 KiB) copied, 0.00384372 s, 171 MB/s
./../mkimage_imx8-soc QX-rev B0-append ahab-container.img-c-scfw scfw_tcm.bin-ap u-boot-atf.bin
a35 0x80000000-out flash.bin
SOC: QX
REVISION: B0
New Container: 0
SCFW:   scfw_tcm.bin
AP:     u-boot-atf.bin    core: a35 addr: 0x80000000
Output: flash.bin
ivt_offset:     1024
rev:    2
Platform:       i.MX8QXP B0
ivt_offset:     1024
container image offset (aligned):9000
flags: 0x10
1+0 records in
1+0 records out
128000 bytes (128 kB, 125 KiB) copied, 0.0012704 s, 101 MB/s
249+1 records in
249+1 records out
127872 bytes (128 kB, 125 KiB) copied, 0.00194118 s, 65.9 MB/s
SCFW file_offset = 0x9000 size = 0x1f400
1+0 records in
1+0 records out
789504 bytes (790 kB, 771 KiB) copied, 0.00209497 s, 377 MB/s
1540+1 records in
1540+1 records out
788824 bytes (789 kB, 770 KiB) copied, 0.00658042 s, 120 MB/s
AP file_offset = 0x28400 size = 0xc0c00
CST: CONTAINER 0 offset: 0x400
CST: CONTAINER 0: Signature Block: offset is at 0x590
DONE.
Note: Please copy image to offset: IVT_OFFSET + IMAGE_OFFSET
```

Note: Keep in mind the offsets above to be used with CST/CSF.

- Please modify csf_boot_image.txt's parameter "File" and "Offset" as shown below:

```
[Authenticate Data]
```

```
 # Binary to be signed generated by mkimage
- File = "flash.bin"
+ File = "./imx-mkimage/iMX8QX/flash.bin"
 # Offsets = Container header  Signature block (printed out by mkimage)
- Offsets   = 0x400          0x590
 + Offsets   = 0x400          0x590
```

5.2.3 Signing the boot image

Now you use the CST to generate the signed boot image from the previously created csf_boot_image.txt commands sequence file:

```
Linux-PC $ cd Secureboot_AIML/
Linux-PC $ ./release/linux64/bin/cst -i csf_boot_image.txt -o flash.signed.bin
Linux-PC $ scp flash.signed.bin <username>@<IP_Addr>:/
```

5.2.4 Flash the signed image

Write the signed U-Boot image:

```
Linux-PC $ sudo dd if=flash.signed.bin of=/dev/<sdX0> bs=1k seek=32 ; sync
```

5.2.5 Prepare the OS container image

You need to generate the OS container image. First, copy the binary previously generated to the <work> directory to save it for later:

```
 Linux-PC $ cd Secureboot_AIML/imx-mkimage
 Linux-PC $ cp iMX8QX/flash.bin ..
 Linux-PC $ make SOC=iMX8QX flash_linux
 Linux-PC $ mv i.MX8QX/flash.bin iMX8QX/flash_os.bin
 Linux-PC $ cp iMX8QX/flash_os.bin ../..

Linux-PC $ cd Secureboot_AIML/
Linux-PC $ ./release/linux64/bin/cst-i csf_linux_img.txt-o os_cntr_signed.bin

Linux-PC $ scp os_cntr_signed.bin local_host@IP:/
```

- Mount the SD-card:

```
Linux-PC $ sudo mount /dev/sdX1 partition
Linux-PC $ sudo cp os_cntr_signed.bin /media/UserID/Boot\ imx8qx
```

```
Linux-PC $ sudo umount partition
```

Then insert the SD-card into the board and connect the serial cable and power on the board.
Two serial consoles are created:

1. U-Boot console (/dev/ttyUSB0)
2. SCFW console (/dev/ttyUSB1)

SCFW Console

```
Linux-PC $sudo minicom-D /dev/ttyUSB1

terminal opens and you got SCFW console given below

Welcome to minicom 2.7

OPTIONS: I18n
Compiled on Nov 15 2018, 20:18:47.
Port /dev/ttyUSB1, 19:49:24

Press CTRL-A Z for help on special keys

>$ seco events
SECO Event[0] = 0x0087EE00
SECO Event[1] = 0x0087EE00
```

SECO Event[0] = 0x0087EE00 [The container image is not signed]
SECO Event[1] = 0x0087EE00 [The container image was signed with wrong key which are not matching the OTP SRK hashes

5.2.6 Dumping SRK Hash fuse values on HOST machine

The SRK Hash fuse values are generated by the srktool and should be programmed in the SoC SRK_HASH [511:0] fuses.

Be careful when programming these values, as this data is the basis for the root of trust. An error in SRK Hash will result in parts that will not boot.

The U-Boot fuse tool can be used for programming e Fuses on i.MX SoCs.

- Dump SRK Hash fuses values on HOST machine:

```
Linux-PC $ od -t x4 SRK_1_2_3_4_fuse.bin
 imx8@VM143:crts$ od -t x4 SRK_1_2_3_4_fuse.bin
0000000 e59aaa4e 97253333 f783083f 7c10bbb3
0000020 8febb2d1 4bf36109 95815423 7c6599af
0000040 ff32c663 4c7b8c5d bb127029 d101fe1d
```

```
0000060 be36af12 37472c1b 7ad6d58c 21253de3
0000100
```

- Switch to uboot console and Program SRK_HASH[511:0] fuses:

```
Linux-PC $sudo minicom-D /dev/ttyUSB0

[U-Boot] Normal Boot
[U-Boot] Hit any key to stop autoboot:  0
=>
```

```
=> fuse prog 0 730 0xe59aaa4e
=> fuse prog 0 731 0x97253333
=> fuse prog 0 732 0xf783083f
=> fuse prog 0 733 0x7c10bbb3
=> fuse prog 0 734 0x8febb2d1
=> fuse prog 0 735 0x4bf36109
=> fuse prog 0 736 0x95815423
=> fuse prog 0 737 0x7c6599af
=> fuse prog 0 738 0xff32c663
=> fuse prog 0 739 0x4c7b8c5d
=> fuse prog 0 740 0xbb127029
=> fuse prog 0 741 0xd101fe1d
=> fuse prog 0 742 0xbe36af12
=> fuse prog 0 743 0x37472c1b
=> fuse prog 0 744 0x7ad6d58c
=> fuse prog 0 745 0x21253de3
```

5.2.7 Verify SECO events

If the fuses have been written properly, there should be no SECO events after boot. To validate this, power on the board, and run the following command on the SCFW terminal:

```
>$ seco events
```

Nothing should be returned after this command.

If you get an error, please refer to examples below:
0x0087EE00 = The container image is not signed.
0x0087FA00 = The container image was signed with wrong key which are not matching the OTP SRK hashes.

If your SRK fuses are not programmed, the event 0x0087FA00 may also be displayed.

Note: The SECO FW v1.1.0 is not logging an invalid image integrity as an event in open mode, in case your image does not boot after moving the lifecycle please review your image setup.

5.2.8 Close the device

After the device successfully boots a signed image without generating any SECO security events, it is safe to close the device. The SECO lifecycle should be changed from 32 (0x20) NXP open to 128 (0x80) OEM closed. Be aware this step could damage your board if any of the previous steps failed and it cannot be reversed. Run on the SCFW terminal:

```
>$ seco lifecycle 16
```

Now reboot the target, and on the same terminal, run:

```
>$ seco info
```

The lifecycle value should now be 128 (0x80) OEM closed.

5.3 Measured Boot with OPTIGA™ TPM2.0

5.3.1 Measured boot Step to verify Platform Integrity

5.3.2 Measuring Kernel Image Hash

Once the Board is booted and Rootfs is mounted on it, a measure of kernel Image will be taken

```
root@imx8qxpaiml:~# $ sha256sum /boot/uImage | cut -d' ' -f1 >> kernel_hash
```

5.3.3 Extending Measured Hash to PCR

Calculated Kernel Image hash will be extended to PCR for Measurement storage.

```
root@imx8qxpaiml:~# $tpm2_pcrextend 16:sha256=$kernel_hash
```

5.3.4 Measuring Content from Specified PCR

Taking the stored value from PCR in order to store in NV-area

```
root@imx8qxpaiml:~# $ tpm2_pcrlist -L sha256:16 -o pcr_kernel_original.bin
```

5.3.5 Generating TPM Measured Boot Policy

Generating a TPM based policy in order to store PCR based architecture value into NV-area

```
root@imx8qxpaiml:~# $ tpm2_createpolicy --policy-pcr -L sha256:16 -F pcr_kernel_original.bin -o
policy_pcr_kernel_original.out
```

5.3.6 Define NV- Area in TPM for PCR Storage

Create an NV -area in order to store the PCR value and specify the policy to it

```
root@imx8qxpaiml:~# $ tpm2_nvdefine -x 0x1500016 -a 0x40000001 -s 32  -L
policy_pcr_kernel_original.out -b
"policyread|policywrite|authread|authwrite|ownerwrite|ownerread"
```

5.3.7 Extending PCR value to Secure NV RAM

Storing the PCR value, the Specified NV-index is defined

```
root@imx8qxpaiml:~# $ tpm2_nvwrite -x 0x1500016 -a 0x1500016 -P pcr:sha256:16
pcr_kernel_original.bin
```

5.3.8 Verifying Platform Integrity Check

Again, reboot the board and perform below steps

```
root@imx8qxpaiml:~# $ sha256sum /boot/uImage | cut -d' ' -f1 >> Measure_kernel_hash
```

```
root@imx8qxpaiml:~# $ tpm2_pcrextend 16:sha256=$kernel_hash
```

```
root@imx8qxpaiml:~# $ tpm2_pcrlist -L sha256:16 -o pcr_kernel_measured.bin
```

```
root@imx8qxpaiml:~# $ tpm2_nvread -x 0x1500016 -a 0x1500016 -s 32 >> pcr_kernel_original.bin
```

```
root@imx8qxpaiml:~# $ cmp pcr_kernel_measure.bin and pcr_kernel_original.bin
```

If values are the same, this verifies the Platform is secure and no tamper has occurred.

6 APPENDIX

6.1 AI_ML 96 Boards

This AI_ML Board i.MX 8QuadXPlus based on 96Boards™ specification. it features the NXP® i.MX 8QXP processor with advanced implementation of the Quad Arm Cortex®-A35+ Arm Cortex®-M4 core, operating at speeds up to 1.2 GHz. Each processor provides a 32-bit DDR3L/LPDDR4 memory interface and other interfaces for connecting peripherals, such as WLAN, Bluetooth™, GPS and camera sensors.

96Boards (http://www.96Boards.org) is a 32-bit and 64-bit ARM® Open Platform hosted by Linaro™ with the intension to serve the software/maker and embedded OEM communities.

Processor

- NXP I.MX 8X Processor
- Quad-core ARM® Cortex® A35 at up to 1.2 GHz per core 64-Bit capable
- 4× Vec4 shaders with 16 execution units optimized for higher performance
- Supports OpenGL 3.0, 2.1, OpenGL ES 3.1, 3.0, 2.0, and 1.1; OpenCL 1.2 Full Profile and 1.1; OpenVG 1.1
- Vulkan High-performance 2D Blit Engine

Memory/Storage

- 2GB LPDDR4 1600MHz
- SD 3.0 (UHS-I)

I/O Interfaces

- Two USB 3.0 Type A connector and one USB 2.0 Micro B
- One 40-pin Low Speed (LS) expansion connector (UART, SPI, I2S, I2C x2, GPIO x12, DC power)
- One 60-pin High Speed (HS) expansion connector (4L-MIPI DSI, USB, I2C x2, 4LMIPI CSI, 1-SPI)
- The board can be made compatible as an add-on mezzanine board

Connectivity

- Bluetooth 4.2 (Bluetooth Low Energy)
- High performance 2.4 GHz and 5 GHz WLAN
- Ethernet support 10/100/1000 Mbps speed

Camera Support

- One 4-lane MIPI-CSI

Video

- H.265 decode (4Kp30)
- H.264 decode (1080p60)
- VP6/VP8 decode (1080p60)
- MPEG-2 decode (1080p60)
- MPEG4, H263, Sorenson Spark decode (1080p)
- Real Video decode (1080p)
- JPEG dec (64K×64K image size)

- H.264 encode (1080p30)
- HDMI

Power, Mechanical and Environmental

- Power: +8.0V to +18V
- Dimensions: 85mm x 100mm
- 96Boards™ Consumer Edition standard dimensions specifications
- Operating Temp: 10°C to +70°C
- RoHS compliant

Software

Yocto based Linux distro 4.14GA release

6.2 AWS Greengrass

AWS IoT Greengrass software extends cloud capabilities to local devices.
Cloud-based management of application logic

- to collect and analyze data
- react autonomously to local events
- Communicate securely on local networks.
- AWS Lambda functions and pre-built connectors to create server less applications that are deployed to devices for local execution.
- provides a local pub/sub message manager that can intelligently buffer messages to preserve inbound and outbound messages to the cloud in case there is no connectivity to cloud

The following diagram shows the basic architecture of AWS IoT Greengrass.

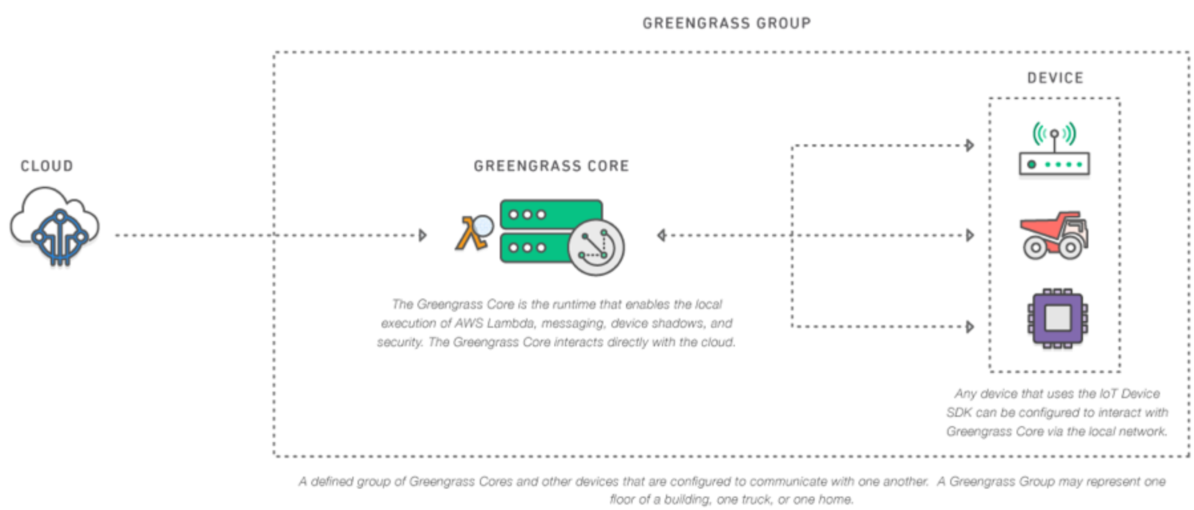


Figure 3: AWS Greengrass Group

AWS IoT Greengrass core software provides the following functionality:

- Deployment and local execution of connectors and Lambda functions.
- Process data streams locally with automatic exports to the AWS Cloud
- MQTT messaging over the local network between devices, connectors, and Lambda functions using managed subscriptions.
- MQTT messaging between AWS IoT and devices, connectors, and Lambda functions using managed subscriptions.
- Secure connections between devices and the AWS Cloud using device authentication and authorization.
- Local shadow synchronization of devices. Shadows can be configured to sync with the AWS Cloud.
- Secure, encrypted storage of local secrets and controlled access by connectors and Lambda functions.
- Automatic IP address detection that enables devices to discover the Greengrass core device.

6.3 Tresor Mezzanine OPTIGA™ TPM 2.0

The Tresor Mezzanine Board provides state-of-the-art secure elements to 96Boards host board. The board is as shown in Figure 2.

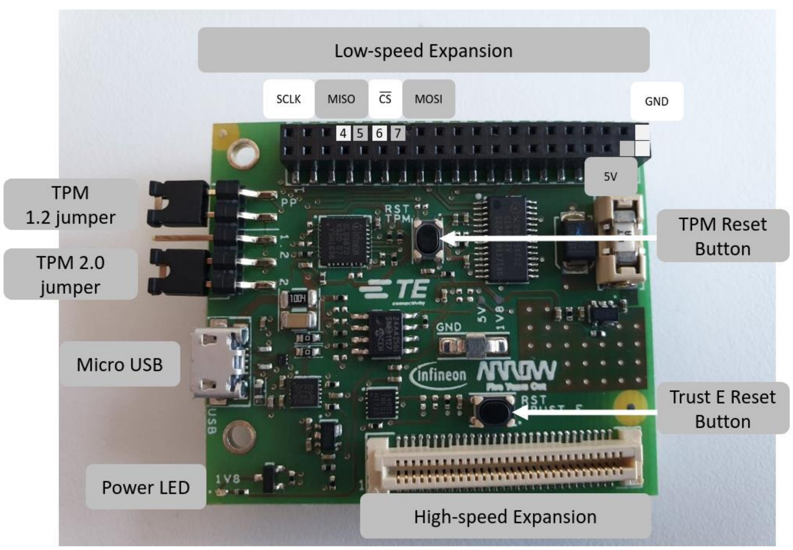


Figure 4: Tresor Mezzanine OPTIGA™ TPM 2.0

The board is equipped with three separate chips that can provide security features

- The SLB9670x provides OPTIGA™ Trusted Platform Module (TPM) 2.0 functionality through SPI communication on the standard 96Boards LS expansion connector.
- The SLB9645x TPM 1.2 chip communicates via I2C on the standard 96Boards low-speed expansion connector.
- The SLS32AIA020A TRUST-E authentication chip, shares the same I2C bus with the TPM 1.2 module.

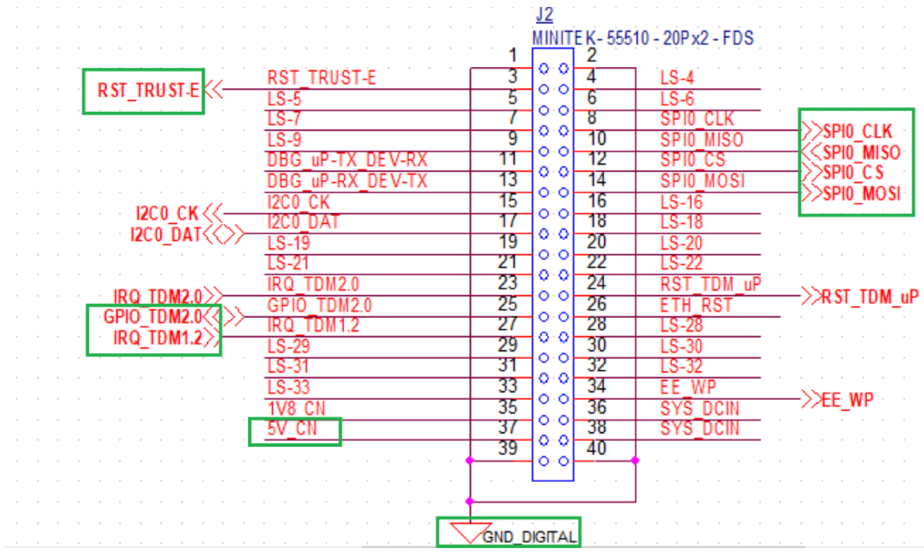


Figure 5: Tresor Mezzanine connector OPTIGA™ TPM 2.0

6.4 Trusted Platform Module – TPM

A cryptographic processor is present on most commercial PCs and servers.
It will typically have three key cryptographic capabilities

- Establishing a root of trust
- Secure boot
- Device identification

Establishing a root of trust

A TPM can prevent a bootkits attack by providing a trusted sequence of boot operations.

The following questions often arise in a running system:

- Is the operating system that is running appropriately secure?
- Is the firmware booting the OS appropriately secure?
- Is the underlying hardware appropriately secure?

Each layer must trust the layer below, as illustrated in the following diagram.

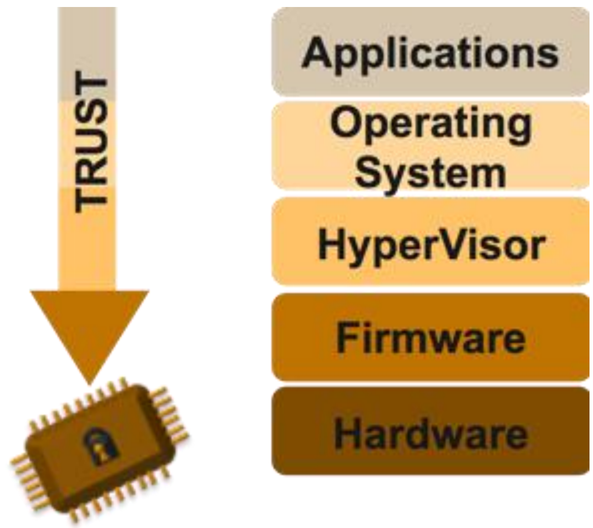


Figure 6: Root of Trust

At the root of this chain is the hardware, which must be inherently trusted. It forms the base on which the chain of trust has been established.

A root of trust is all of the following:

- Set of functions in a trusted computing module that is always trusted by the firmware/OS
- Prerequisite for secure boot process
- Component that helps in detection of boot kits

Secure boot

A secure boot builds on the underlying notion of a root of trust to protect the boot process from being compromised on the device.
In case a chain of trust is broken, the boot process is aborted and the device attempts to go back to its last known good state. An extension to secured boot process is a measured boot – where the device does not halt the boot process. Instead, it records the identity of each component that participates in the boot process so that the component identities can be verified against a list of approved component identities for that device. This is called a measured boot.

These two processes are illustrated in the following diagram.

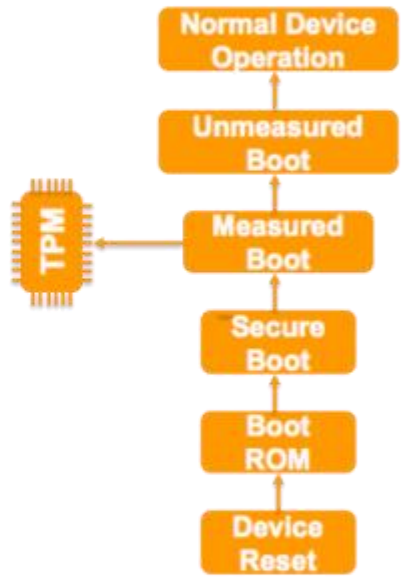


Figure 7: Measured/Trusted Boot Process

A typical sequence of a measured boot is as follows:

- The boot ROM acts as the Root of Trust.
- Upon a device reset, each image that forms part of the boot sequence is validated (measured) before execution.
- The measurements are stored in a TPM.
- Each measurement serves as the proxy for the Root of Trust for the subsequent step in the boot sequence.
- Normally, only critical and security-sensitive process and configuration files are considered for the measurement.
- After the security-sensitive processes are completed, the device enters the unmeasured boot stage before entering normal system operation state.

Device identification

- Check the identity of the device that is communicating with the messaging gateway.
- Generate key pairs for the devices, which are then used to authenticate and encrypt the traffic
- TPM stores the keys in tamper-resistant hardware.
- The keys are generated using TPM itself and are thereby protected from being retrieved by external programs.

The rest of this post focuses on how to integrate and use features of TPMs to protect the edge gateways running AWS IoT Greengrass. This integration uses the PKCS#11 protocol as the interface to the TPM.

6.5 iMX8X Secure Boot Overview

6.5.1 Secure AHAB boot architecture

The AHAB secure boot feature relies on digital signatures to prevent unauthorized software execution during the device boot sequence. In case a malware takes control of the boot sequence, sensitive data, services and network can be impacted.

The AHAB authentication is based on public key cryptography in which image data is signed offline using one or more private keys. The resulting signed image data is then verified on the i.MX processor using the corresponding public keys. The public keys are included in the final binary and the SRK Hash is programmed in the SoC fuses for establishing the root of trust.

On i.MX 8 and i.MX 8X families, the SCU is responsible to interface with the boot media, managing the process of loading the firmware and software images in different partitions of the SoC. The SECO is responsible to authenticate the images, authorizing the execution of them.

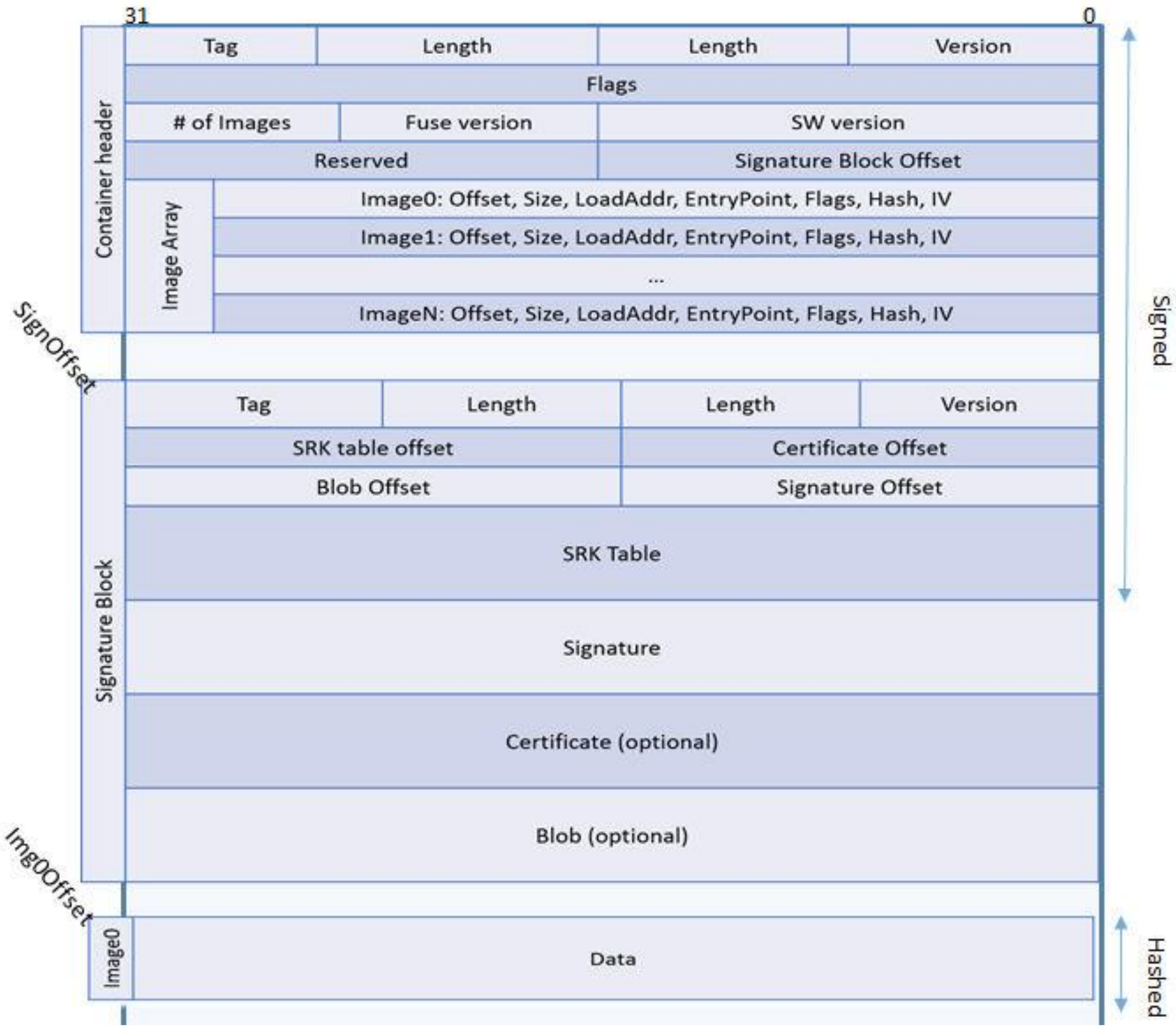


Figure 8: Container layout

The SRK Table is generated with the SRK Tool, provided with the Code Signing Tool (CST).

6.5.1.1 The System Control Unit (SCU)

The System Control Unit SCU is a subsystem equipped with a programmable M4 core, which is responsible to handle the resource allocation, power, clocking, IO configuration and muxing.

The SCU is also responsible to interface between the rest of the system. In the secure boot flow the SCU interfaces with the Security Controller (SECO), requesting the image authentication.

The System Control Unit FW (SCFW) is responsible to control all the functionalities of the SCU. This firmware is distributed in a porting kit form. Instructions to download the SCFW Porting Kit are available in the Linux BSP Release Notes.

Details about SCU can be found in the processors Reference Manual (RM).

6.5.1.2 The Security Controller (SECO)

The SECO is a M0+ core dedicated to handle the SoC security subsystem. The controller communicates with SCU domain through a dedicate message unit (MU).

The SECO has a dedicate ROM which is responsible to initialize low level security features and to authenticate the SECO firmware previously loaded by the SCU ROM.

The SECO firmware provides security services at run-time to different domains of the SoC, one of these being the capability to authenticate images.

The SECO firmware is signed and distributed by NXP and is always authenticated in OEM open and closed configuration, instructions to download the SECO FW are available in the Linux BSP Release Notes.

Details about SECO can be found in the processors Security Reference Manual (SRM).

6.5.1.3 The Image Container

Due to the new the architecture, multiple firmware and software are required to boot i.MX8 and i.MX8x family devices.

In order to store all the images in a single binary the container image structure is used.

At least two containers are needed for the boot process, the first container must include only the SECO FW (provided by NXP). Additional containers can contain one or multiple images, depending on the user's specific application.

The final binary is generated by the imx-mkimage tool. The tool can generate additional containers and combine all containers in a single binary.

6.5.1.4 Secure boot flow

Due to the multicore architecture, the i.MX 8 boot sequence involves SCU ROM, SCU Firmware, SECO ROM, and SECO FW.

Figure 9 below illustrates the secure boot flow overview.

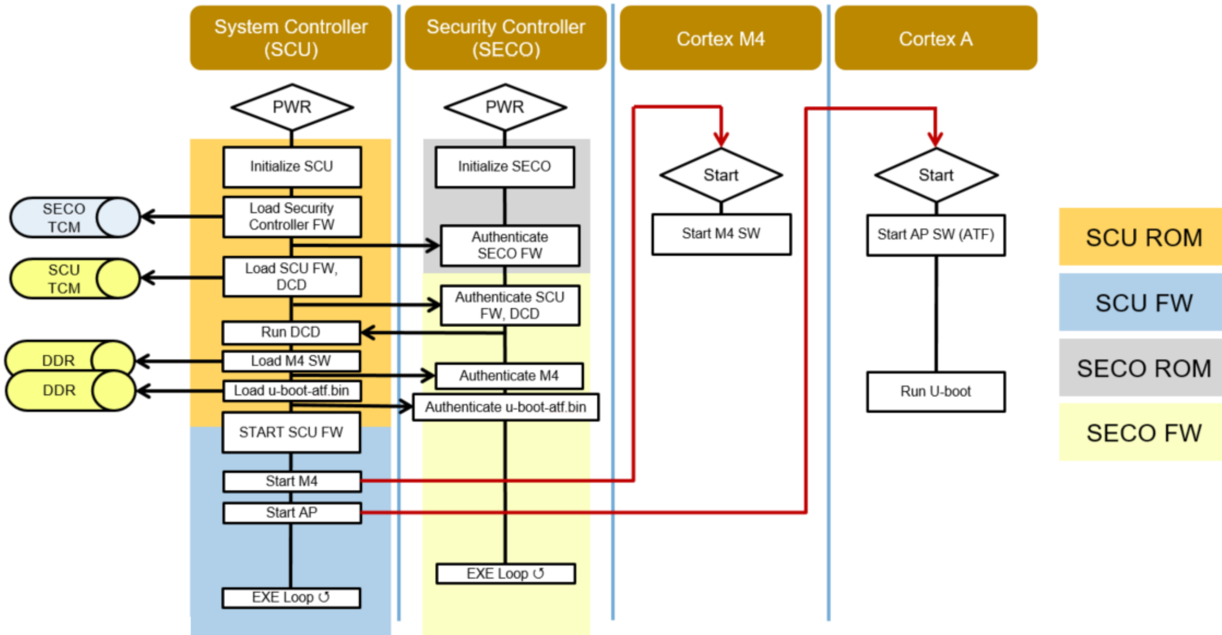


Figure 9: Secure boot flow overview

The i.MX8 and i.MX8x boot flow is as follows.

1. At reset, the SCU ROM and SECO ROM both start execution.
2. The SCU ROM reads the boot configuration and loads the SECO FW (first container) from the boot media to the SECO TCM.
3. A message is send by the SCU ROM via MU requesting the SECO ROM to authenticate the SECO FW, which is signed using NXP key.
4. The SCU ROM loads the second container from the boot media, this container must contain at least the SCFW, which is signed using the OEM keys.
5. The SCU ROM loads the SCFW to the SCU TCM; a message is send via MU requesting the SECO FW to authenticate the SCU FW and DCD table.
6. The SCU ROM configures the DDR and loads the M4 and AP images to their respective load addresses.
7. The SCU ROM requests the SECO FW to authenticate the M4 image.
8. The SCU ROM requests the SECO FW to authenticate the AP image.
9. The SCU FW is initialized and starts the Arm®
   Cortex® -M and Cortex-A cores.

After each authentication, SECO FW returns a success or failure status to SCU.
If SCU receives a fail response from SECO FW authentication while attempting to boot from the primary boot source, the SCU will attempt to boot from the secondary boot source (if any).

If SCU receives a fail response from SECO FW authentication while attempting to boot from the secondary boot source, the SCU will got into recovery mode.
If the SCU receives a fail response for the second container, the SCU will enter the recovery mode

6.5.1.5 AHAB Secure Boot Proces Overview

The boot image is composed of different layers, as shown in Figure 3 below.

Figure 10: Secure boot image layout

The boot image contains two containers, one for the SECO firmware (AHAB), and one for the SCFW, the ATF, U-Boot and M4 Image. They are preceded by their headers. The first one, containing the SECO firmware image, is padded to 0x1000 to fix the start address of the second one, which can contain one or multiple images.

NOTE

The only required images for the device are the SECO FW and the SCFW. The Cortex-A or Cortex-M images may or may not be part of it depending on the OEMs system design

In contrast with the secure boot process used in the HABv4 architecture, there is no need for CSF in this architecture. The CST is responsible to handle the signature block, as shown in Figure 4 below

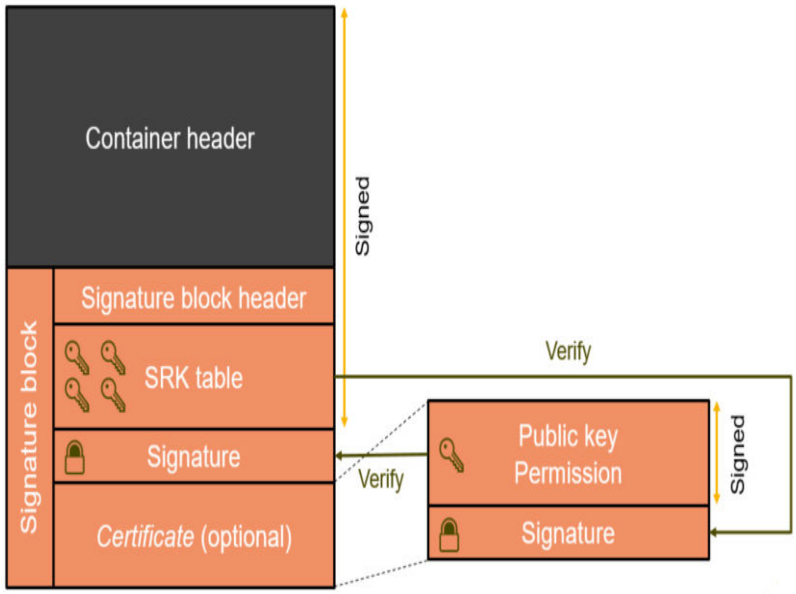


Figure 11: Signature block

The container signature is verified against the SGK key certificate, which is then verified against the SRK table. If the subordinate key is not used, the container signature is directly verified against the SRK keys.

This document describes a step-by-step procedure on how to sign and securely boot a flash.bin image. It is assumed that the reader is familiar with basic AHAB concepts and with the PKI tree generation.

It is also assumed that the reader is familiar with all pieces of software needed. The procedure to build SCFW, ATF and download the firmwares are out of scope of this document, please refer to the Linux BSP Release Notes and AN12212[1] for further details.

Details about AHAB can be found in the introduction_ahab.txt document and in processors Security Reference Manual Document (SRM).

6.5.1.6 Architecture an image supporting secure boot

The boot image is composed of different layers:

```
+---------------------------+ <-- *start
|   1st Container header    |
|       and signature       |
+---------------------------+
| Padding for 1kB alignment |
+---------------------------+ <-- *start + 0x400
|   2nd Container header    |
|       and signature       |
+---------------------------+
|          Padding          |
+---------------------------+
|          SECO FW          |
+---------------------------+
|          Padding          |
+---------------------------+
|      SCU FW with DDR      |
|   initialization Image    |
|         embedded          |
+---------------------------+
|      Cortex-M4 Image      |
+---------------------------+
|    Cortex-A bootloader    |
+---------------------------+
```

It contains two containers, one for the SECO firmware (AHAB), and one for the SCFW, the ATF, U-Boot and M4 Image. Their headers precede them. The first one, containing the SECO firmware image, is padded to 0x1000 to fix the start address of the second one, which can contain one or multiple images.

If you are familiar with secure boot process with HABv4, you will notice there is no need for CSF in this architecture. The CST is responsible to handle the Signature block:

```
+---------------------------+   ^
|                           |   |
|                           |   |
|      Container header     |   |
|                           |   |
|                           |   |
+---+-----------------------+   |
| S | Signature block header|   | Signed
| i +-----------------------+   |
| g |                       |   |
| n |                       |   |
| a |       SRK table       |   |
| t |                       |   |
| u |                       |   |
| r +-----------------------+   v
| e |       Signature       |
|   +-----------------------+
| b |                       |
| l |       SGK Key         |
| o | Certificate (optional)|
| c |                       |
| k |                       |
+---+-----------------------+
```

The certificate block is divided into:

```
+---------------+ ^
|  Public key   | | Signed
|  Permission   | |
+---------------+ v
|   Signature   |
+---------------+
```

The first block (public key permission) verifies the Signature block preceding (between SRK table and Certificate blocks), while the second block (signature) is verified by the SRK table block.

6.6 Measured boot Principles

Measuring boot is a way to inform the last software stage if someone tampered with the platform. It is impossible to know what has been corrupted exactly, but knowing someone has is already enough to not reveal secrets. Indeed, TPMs offer a small secure locker where users can store keys, passwords, authentication tokens, etc. These secrets are not exposed anywhere (unlike with any standard storage media) and TPMs have the capability to release these secrets only under specific conditions. Here is how it works.

Starting from a *root of trust* (typically the SoC Boot ROM), each software stage during the boot process (BL1, BL2, BL31, BL33/U-Boot, Linux) is supposed to do some measurements and store them in a safe place. A *measure* is just a digest (let's say, a SHA256) of a memory region. Usually **each stage will 'digest' the next one**. Each digest is then sent to the TPM, which will *merge* this measurement with the previous ones.

The hardware feature used to store and merge these measurements is called **Platform Configuration Registers (PCR)**. At power-up, a PCR is set to a known value (either 0x00s or 0xFFs, usually). Sending a digest to the TPM is called extending a PCR because the chosen register will extend its value with the one received with the following logic:

PCR[x] := sha256(PCR[x] | digest)

This way, a PCR can only evolve in one direction and never go back unless the platform is reset.
In a typical measured boot flow, a TPM can be configured to disclose a secret only under a certain PCR state. Each software stage will oversee extending a set of PCRs with digests of the next software stage. Once in Linux, user software may ask the TPM to deliver its secrets but the only way to get them is having all PCRs matching a known pattern. This can only be obtained by extending the PCRs in the right order, with the right digests.

7 REFERENCES

[1] https://www.yoctoproject.org/docs/latest/bitbake-user-manual/bitbake-user-manual.html

[2] https://patchwork.kernel.org/patch/10750087/

[3] https://git.yoctoproject.org/cgit/cgit.cgi/meta-security

[4] https://docs.aws.amazon.com/greengrass/latest/developerguide/gg-dg.pdf

[5] https://docs.aws.amazon.com/iot/latest/developerguide/register-CA-cert.html

[6] https://www.infineon.com/dgdl/Infineon-SLB%209670VQ2.0-DataSheet-v01_04-EN.pdf?fileId=5546d4626fc1ce0b016fc78270350cd6

[7] https://github.com/tpm2-software

[8] CST_TOOL

[9] U-Boot Project, on the imx_v2018.03_4.14.78GA release branch (initial release)