Designing a Secure OTA Update Implementation

August, 2018

Nick Lethaby, IoT Ecosystem Manager, Texas Instruments

Richard Barry, Principal Engineer, AWS

Introduction

An OTA (Over-The-Air) update is a method of distributing and installing new firmware software updates via wireless connections

The ability to perform OTA updates is critical to IoT applications as it allows low-cost patching of bugs and security vulnerabilities, as well as addition of new features

In this webinar, we will examine

1 The potential for OTA updates to impact security and reliability

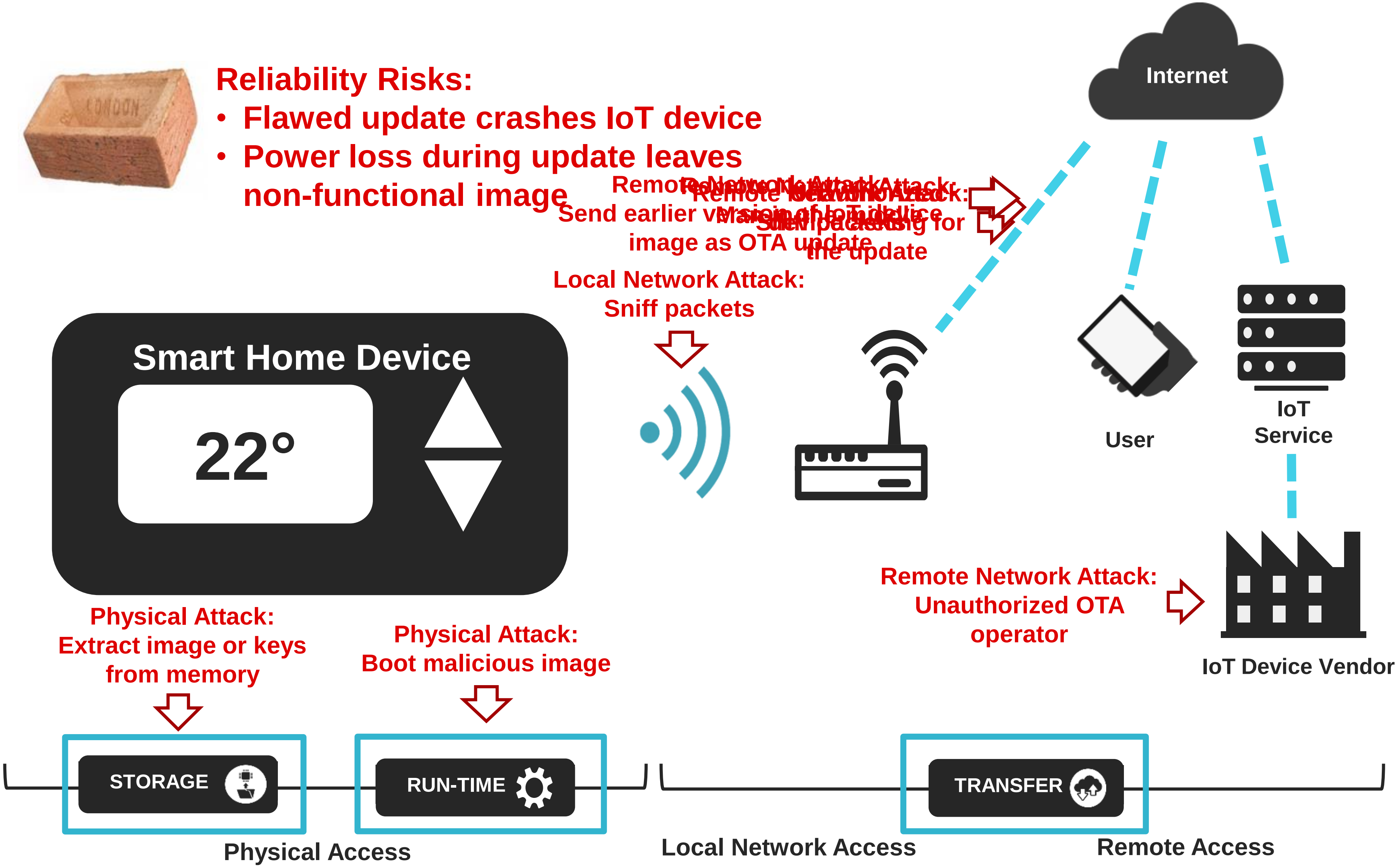
2 An OTA update solution based on an integration of Amazon FreeRTOS with the Texas instruments SimpleLink Wi-Fi microcontrollers and how this addresses security and reliability concerns via:

- Cloud-based services
- Embedded software
- Hardware architecture

OTA Updates: Understanding the risks

Reliability Risks:

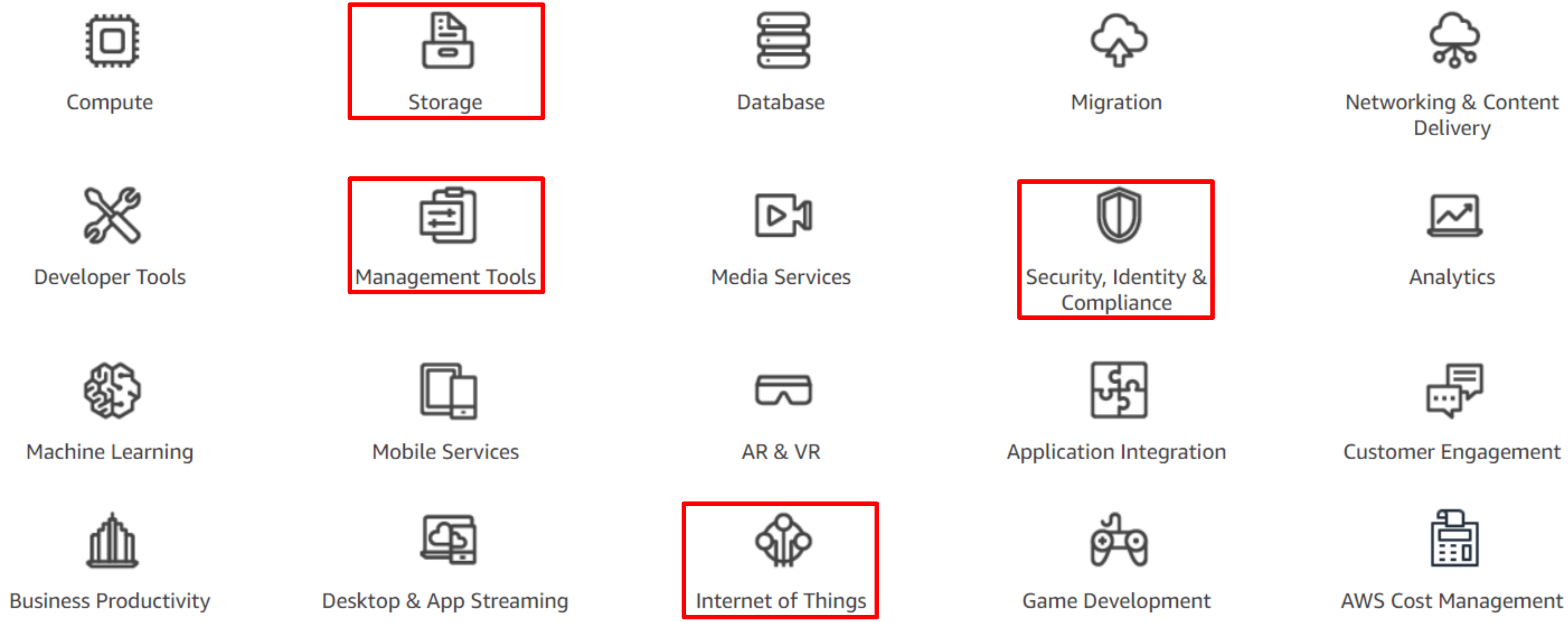
- **Flawed update crashes IoT device**
- **Power loss during update leaves non-functional image**



AWS Cloud Computing

- Compute
- Storage
- Database
- Migration
- Networking & Content Delivery
- Developer Tools
- Management Tools
- Media Services
- Security, Identity & Compliance
- Analytics
- Machine Learning
- Mobile Services
- AR & VR
- Application Integration
- Customer Engagement
- Business Productivity
- Desktop & App Streaming
- Internet of Things
- Game Development
- AWS Cost Management

AWS Cloud Computing - OTA



Compute

Storage

Database

Migration

Networking & Content Delivery

Developer Tools

Management Tools

Media Services

Security, Identity & Compliance

Analytics

Machine Learning

Mobile Services

AR & VR

Application Integration

Customer Engagement

Business Productivity

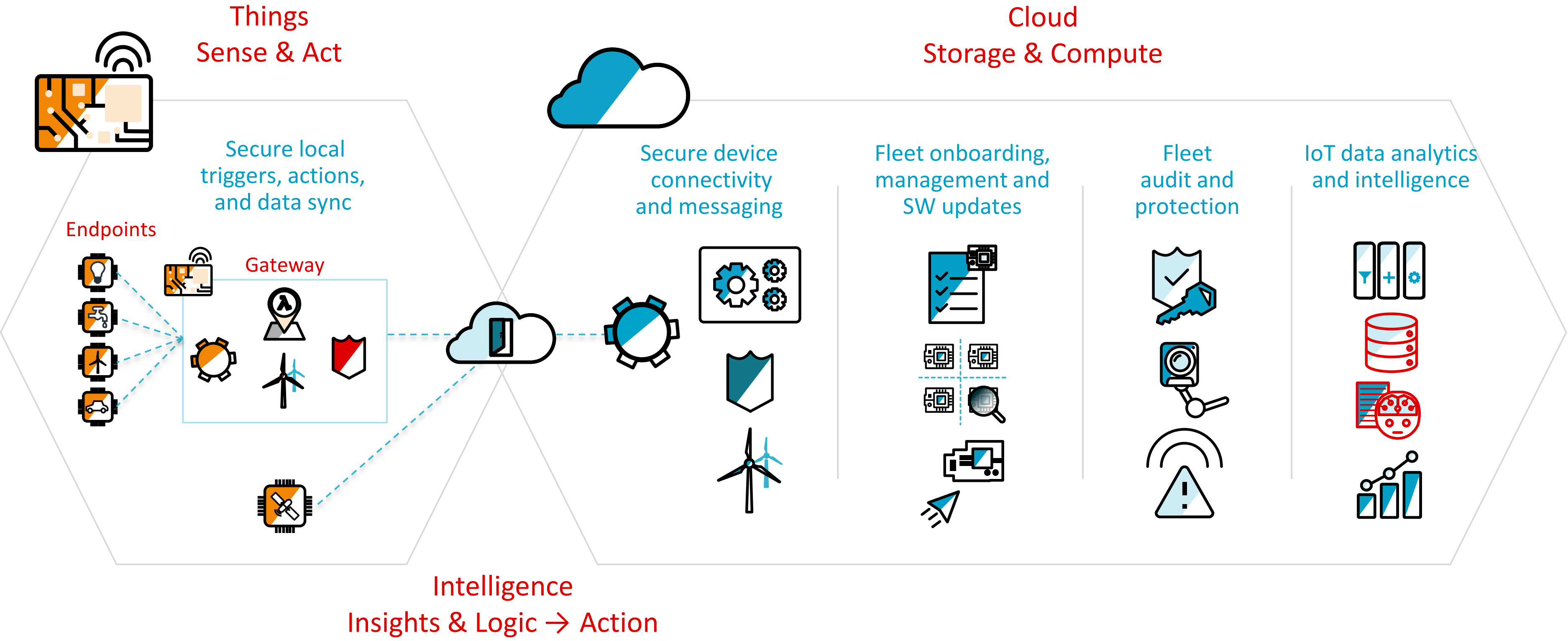
Desktop & App Streaming

Internet of Things

Game Development

AWS Cost Management

AWS IoT Architecture



Things
Sense & Act

Cloud
Storage & Compute

Secure local triggers, actions, and data sync

Secure device connectivity and messaging

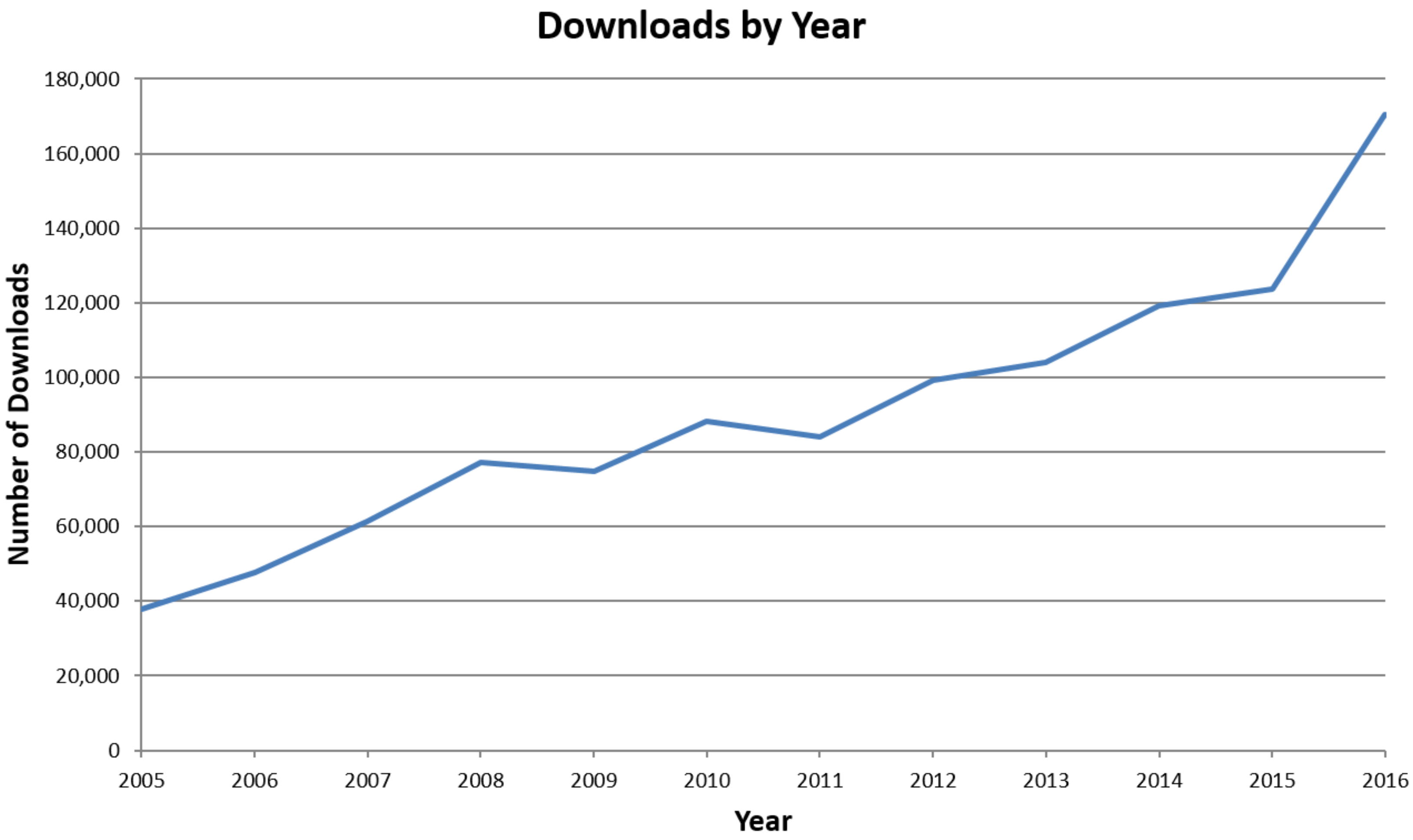
Fleet onboarding, management and SW updates

Fleet audit and protection

IoT data analytics and intelligence

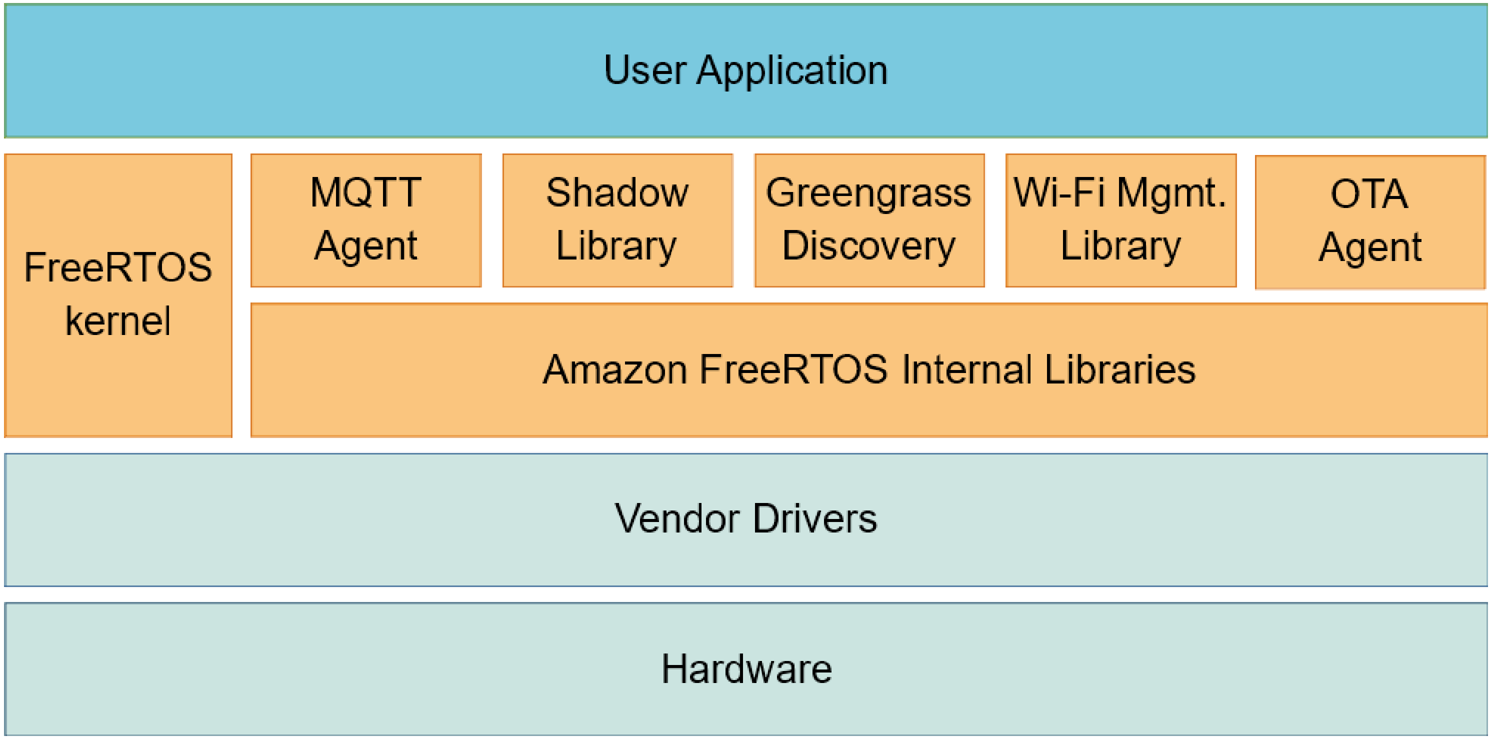
Intelligence
Insights & Logic → Action

FreeRTOS Kernel



Amazon FreeRTOS

- Augments FreeRTOS kernel with functionality that enables MCUs to securely connect to cloud services
- Completely free to use for any application
- Open source MIT license



User Application

FreeRTOS kernel

MQTT Agent

Shadow Library

Greengrass Discovery

Wi-Fi Mgmt. Library

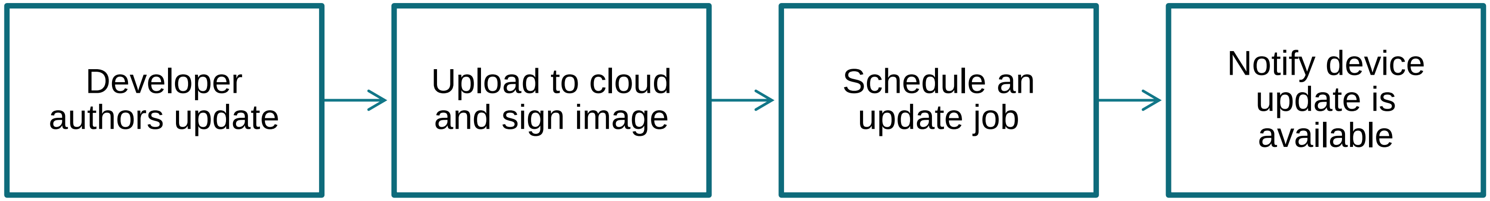
OTA Agent

Amazon FreeRTOS Internal Libraries

Vendor Drivers

Hardware

OTA on Amazon FreeRTOS: User Actions



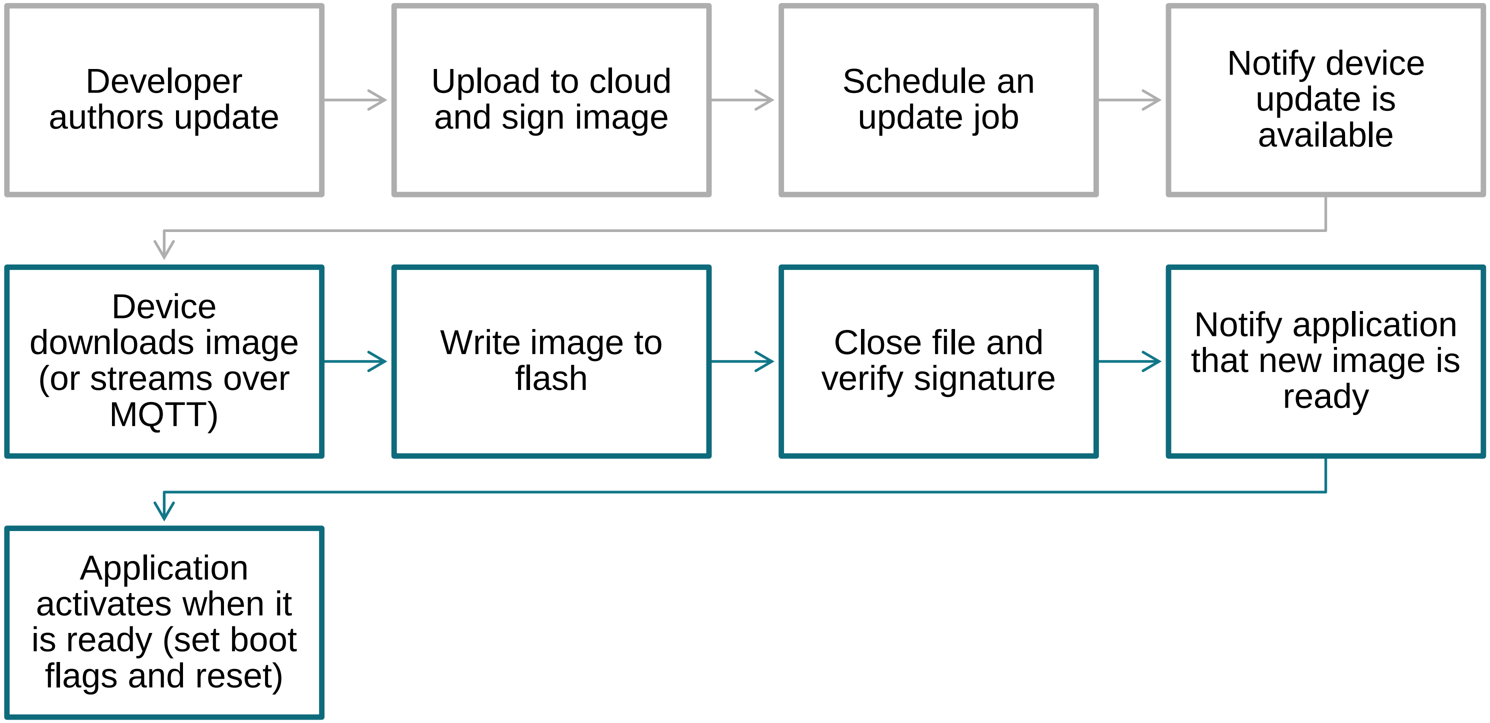
Developer authors update

Upload to cloud and sign image

Schedule an update job

Notify device update is available

OTA on Amazon FreeRTOS: Agent Actions



Developer authors update

Upload to cloud and sign image

Schedule an update job

Notify device update is available

Device downloads image (or streams over MQTT)

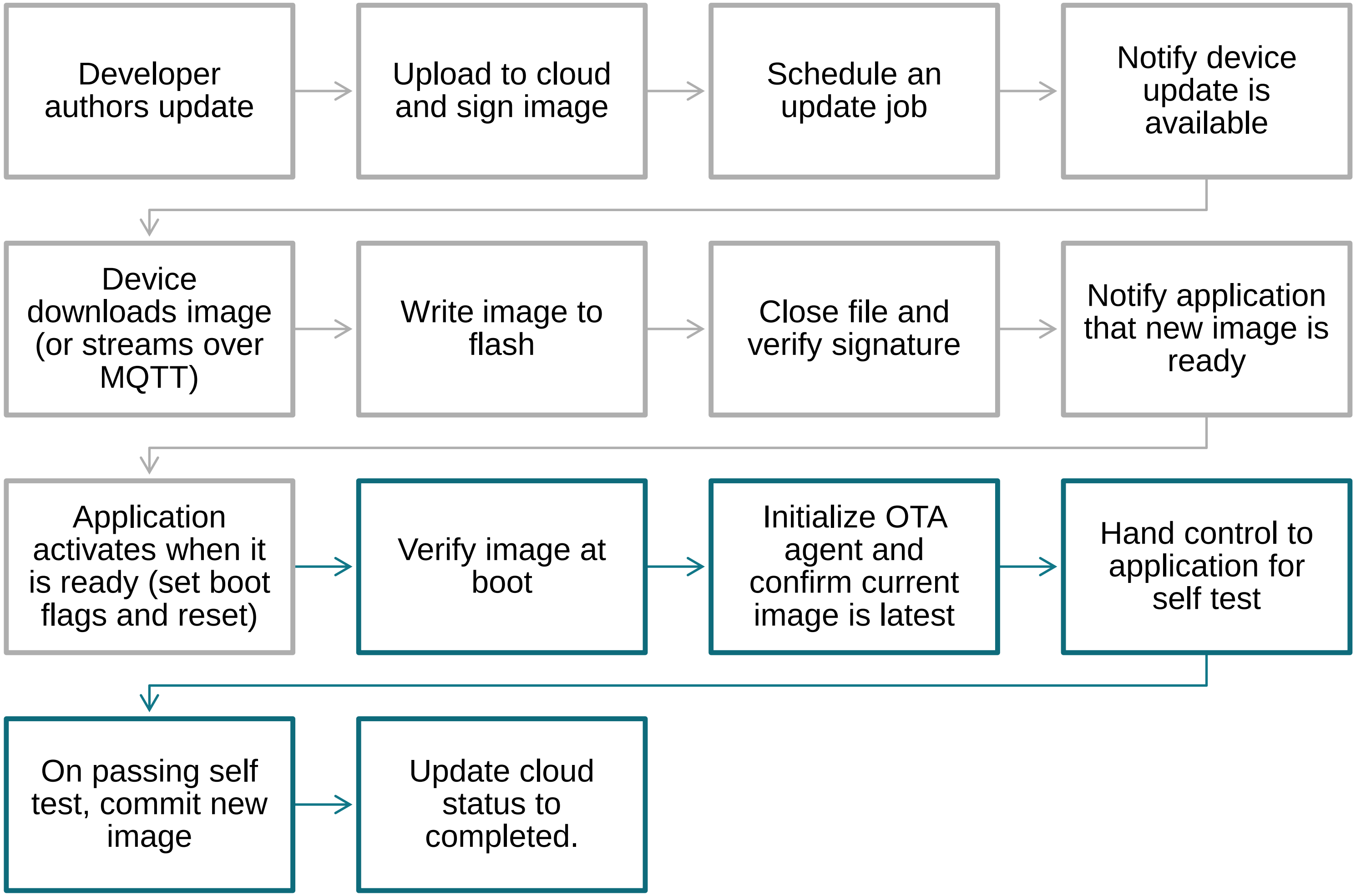
Write image to flash

Close file and verify signature

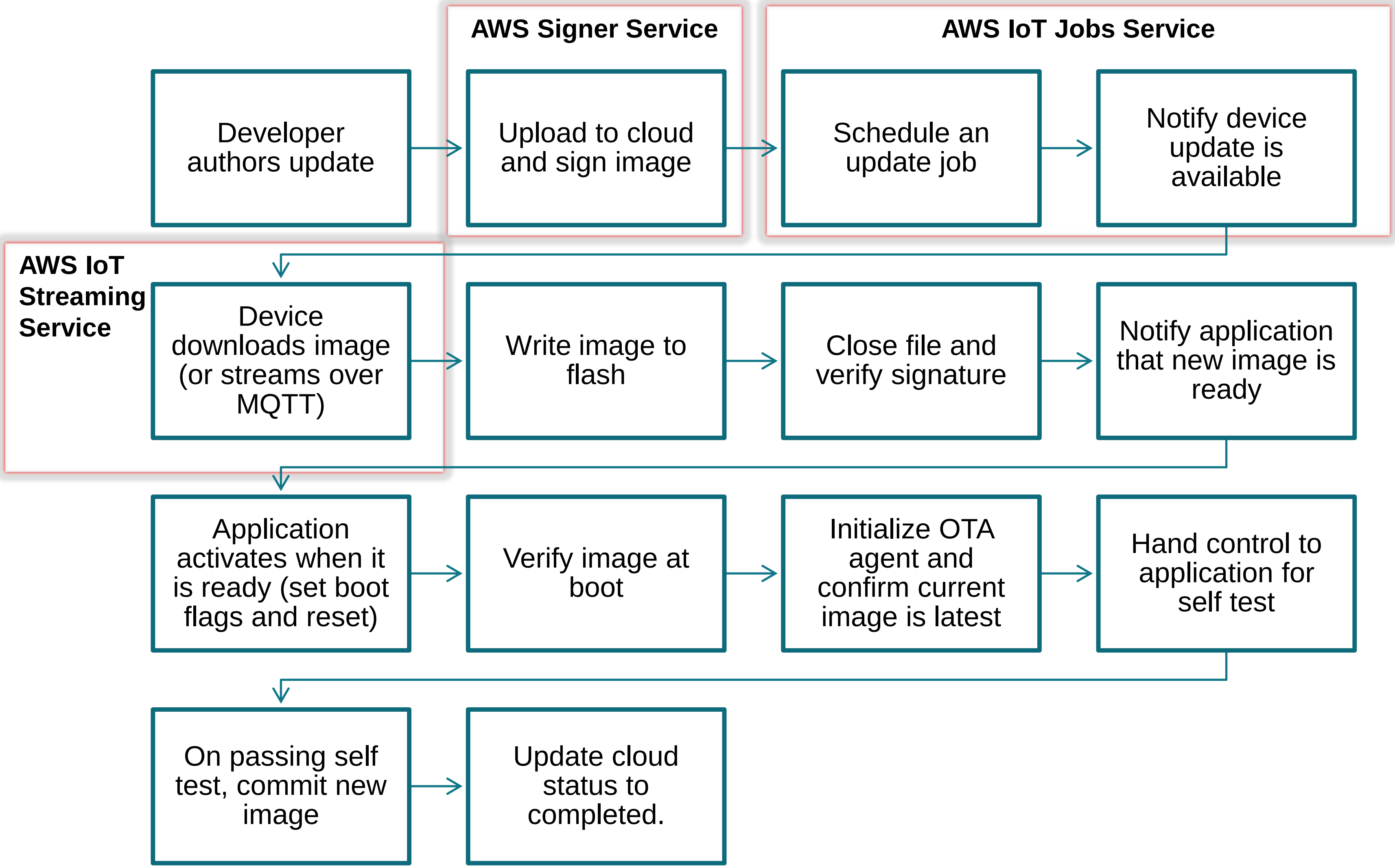
Notify application that new image is ready

Application activates when it is ready (set boot flags and reset)

OTA on Amazon FreeRTOS: Reboot Actions

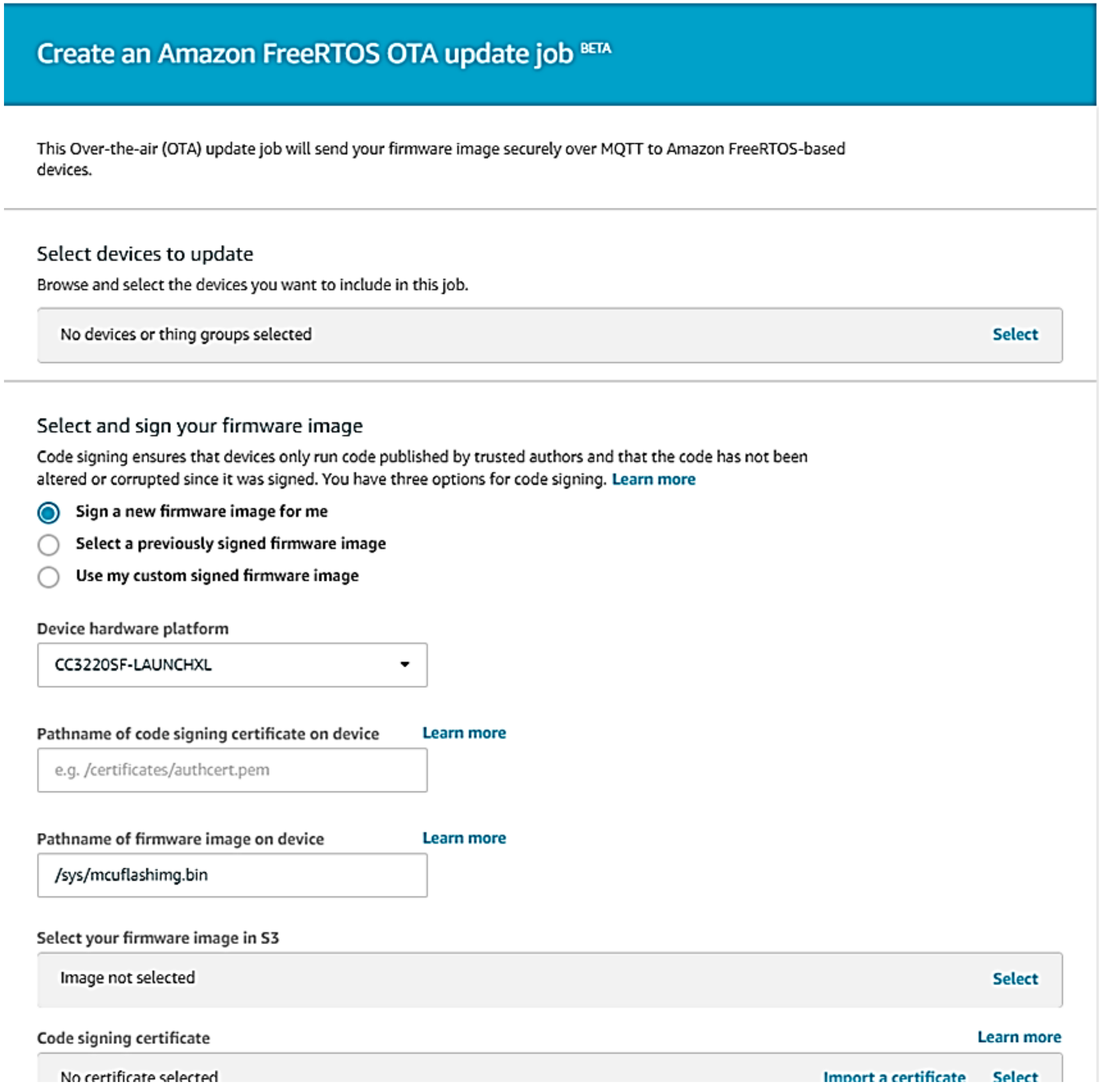

Developer authors update
Upload to cloud and sign image
Schedule an update job
Notify device update is available
Device downloads image (or streams over MQTT)
Write image to flash
Close file and verify signature
Notify application that new image is ready
Application activates when it is ready (set boot flags and reset)
Verify image at boot
Initialize OTA agent and confirm current image is latest
Hand control to application for self test
On passing self test, commit new image
Update cloud status to completed.

OTA on Amazon FreeRTOS: An Overview


AWS Signer Service
AWS IoT Jobs Service
Developer authors update
Upload to cloud and sign image
Schedule an update job
Notify device update is available
AWS IoT Streaming Service
Device downloads image (or streams over MQTT)
Write image to flash
Close file and verify signature
Notify application that new image is ready
Application activates when it is ready (set boot flags and reset)
Verify image at boot
Initialize OTA agent and confirm current image is latest
Hand control to application for self test
On passing self test, commit new image
Update cloud status to completed.

Code Signing Service

- Amazon FreeRTOS OTA updates require a signed image
- The IoT device can authenticate the source of the OTA image
- The signing service is integrated with the Amazon Certificate Manager (ACM)
- Device providers register their code signing certificate with the ACM



Create an Amazon FreeRTOS OTA update job BETA

This Over-the-air (OTA) update job will send your firmware image securely over MQTT to Amazon FreeRTOS-based devices.

Select devices to update

Browse and select the devices you want to include in this job.

No devices or thing groups selected Select

Select and sign your firmware image

Code signing ensures that devices only run code published by trusted authors and that the code has not been altered or corrupted since it was signed. You have three options for code signing. Learn more

● Sign a new firmware image for me

○ Select a previously signed firmware image

○ Use my custom signed firmware image

Device hardware platform

CC3220SF-LAUNCHXL ▾

Pathname of code signing certificate on device Learn more

e.g. /certificates/authcert.pem

Pathname of firmware image on device Learn more

/sys/mcuflashimg.bin

Select your firmware image in S3

Image not selected Select

Code signing certificate Learn more

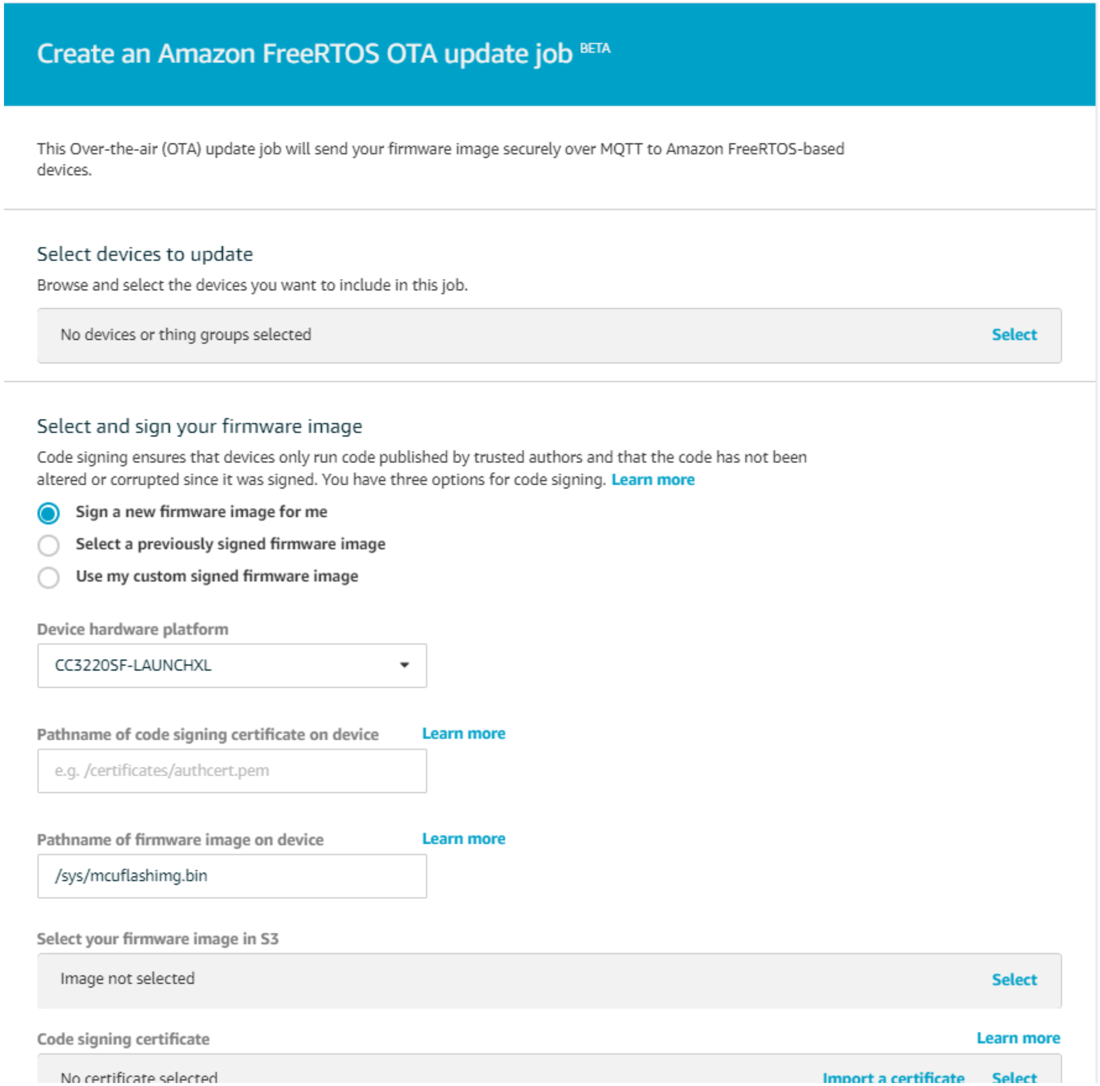
No certificate selected Import a certificate Select

Job Service (Scheduling Updates)

- OTA uses the AWS IoT Job Service

- The Job Service is used to define a set of remote operations (OTA is the operation in this case)

- You specify a list of targets to perform that job (a device group in this case)



Create an Amazon FreeRTOS OTA update job BETA

This Over-the-air (OTA) update job will send your firmware image securely over MQTT to Amazon FreeRTOS-based devices.

Select devices to update

Browse and select the devices you want to include in this job.

No devices or thing groups selected — Select

Select and sign your firmware image

Code signing ensures that devices only run code published by trusted authors and that the code has not been altered or corrupted since it was signed. You have three options for code signing. Learn more

● Sign a new firmware image for me

○ Select a previously signed firmware image

○ Use my custom signed firmware image

Device hardware platform: CC3220SF-LAUNCHXL

Pathname of code signing certificate on device — Learn more: e.g. /certificates/authcert.pem

Pathname of firmware image on device — Learn more: /sys/mcuflashimg.bin

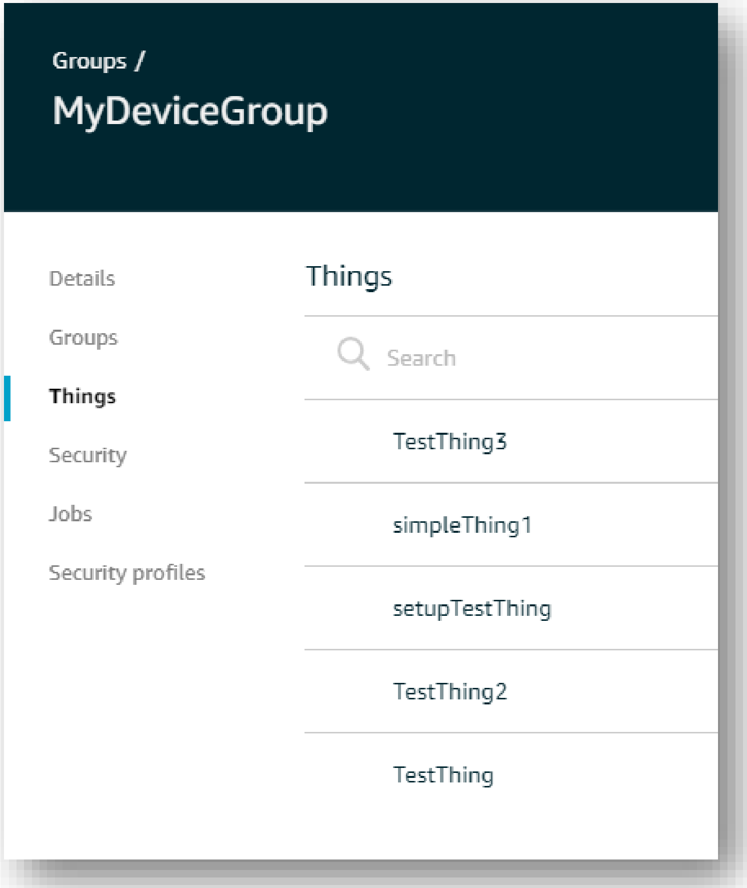
Select your firmware image in S3: Image not selected — Select

Code signing certificate — Learn more

No certificate selected — Import a certificate — Select

Thing Groups

- Manage several devices/things at once by categorizing them into groups.
- Send OTA images to individual devices, or all devices in a group



Groups /

MyDeviceGroup

TestThing3

simpleThing1

setupTestThing

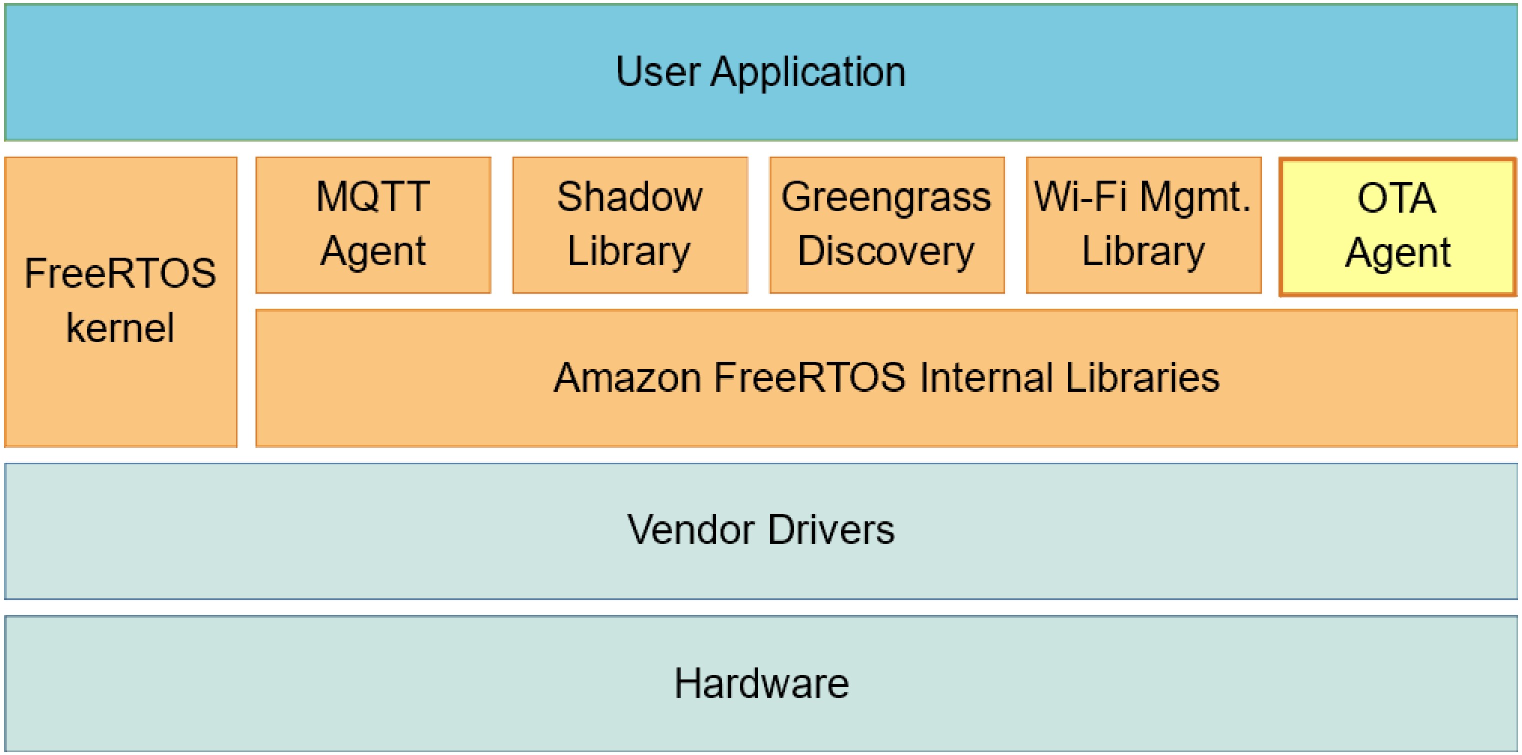
TestThing2

TestThing

```
{   "thingGroups": [
     {
         "groupName": "LightBulbs",
         "groupArn": "arn:aws:iot:us-west-2:thinggroup/LightBulbs"
     },
     {
         "groupName": "RedLights",
         "groupArn": "arn:aws:iot:us-west-2:thinggroup/RedLights"
     },
]}
```

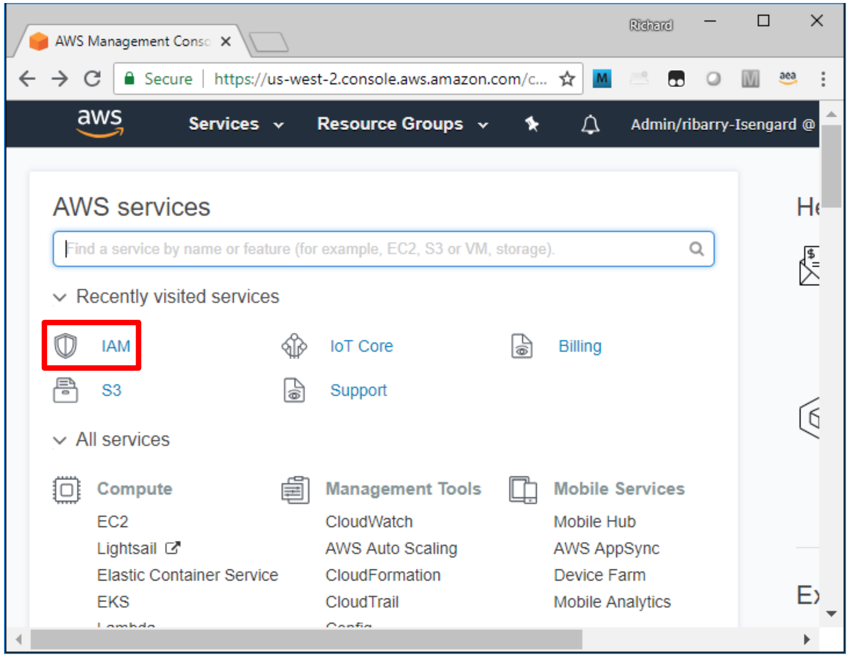
Device Side OTA Agent

- Uses MQTT Streaming Service and all communications through a single TLS connection
- Minimizes resource usage by downloading OTA via the existing TLS connection used for MQTT communication with AWS IoT



Cloud Operator Security Starts with IAM

- Identity and Access Management (IAM) lets you manage access to AWS services and resources securely
- Create and manage AWS users and groups
- Use permissions to allow and deny their access to AWS resources



IAM Users, Roles and Policies

- **IAM Users** allow you to define specific users of an AWS account with different permissions
- **IAM Roles** allow applications to access AWS services programmatically with specified permissions
- **IAM Policies** are documents that define the fine-grained permissions for each IAM User and Role

SAMPLE POLICY

```
    {
        "Version": "2012-10-17",
        "Statement": [
          {
            "Sid": "FullAccess",
            "Effect": "Allow",
            "Action": ["s3:*"],
            "Resource": ["*"]
          },
          {
            "Sid": "DenyCustomerBucket",
            "Action": ["s3:*"],
            "Effect": "Deny",
            "Resource":
    ["arn:aws:s3:::customer",
     "arn:aws:s3:::customer/*" ]
          }
        ]
     }
```

Preventing Unauthorized Job Operators

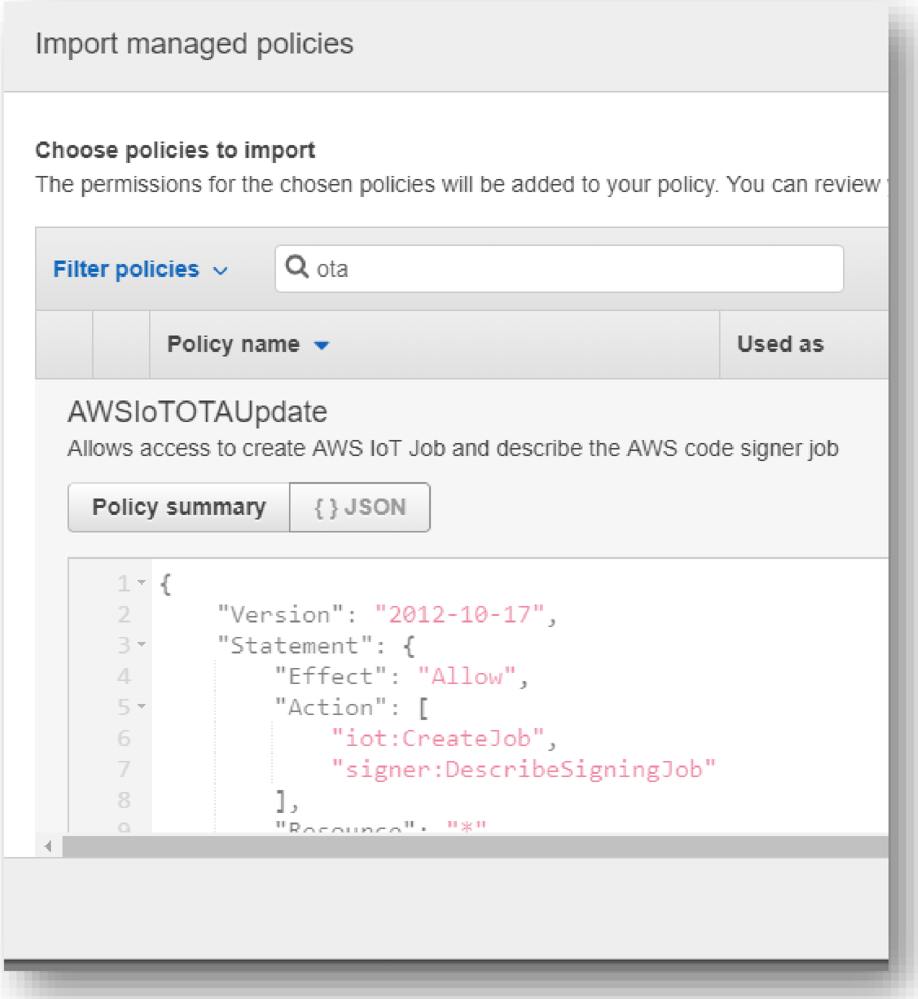
- An OTA User Policy grants your IAM user access to a number of job-related and OTA services.
- The following actions are performed during the FreeRTOS OTA workflow, and the following policies are therefore needed the IAM user.

```
"s3:ListBucket",
"s3:ListAllMyBuckets",
"s3:CreateBucket",
"s3:PutBucketVersioning",
"s3:GetBucketLocation",
"s3:GetObjectVersion",

"acm:ImportCertificate",
"acm:ListCertificates",

"iot:ListThings",
"iot:ListThingGroups",
"iot:CreateStream",
```

```
"iot:CreateOTAUpdate",
"iot:GetOTAUpdate",
"iot:ListJobs",
"iot:ListJobExecutionsForJob"
,
"iot:DescribeJob",
"iot:GetJobDocument",
"iam:ListRoles",

"signer:ListSigningJobs",
"signer:StartSigningJob",
"signer:DescribeSigningJob"
```

Managed (Pre-Configured) Access Policies

- The OTA Service Role is a role that AWS IoT takes on to perform OTA actions on your behalf
- An AWS managed policy is a standalone policy that is created and administered by AWS, making it easier for you to assign appropriate permissions.
- Create a role, and add permissions to it using the managed policy called ***AWSIoTOTAUpdate***, which contains the permissions needed for AWS IoT to create jobs and use signed images.



Import managed policies

Choose policies to import

The permissions for the chosen policies will be added to your policy. You can review

AWSIoTOTAUpdate

Allows access to create AWS IoT Job and describe the AWS code signer job

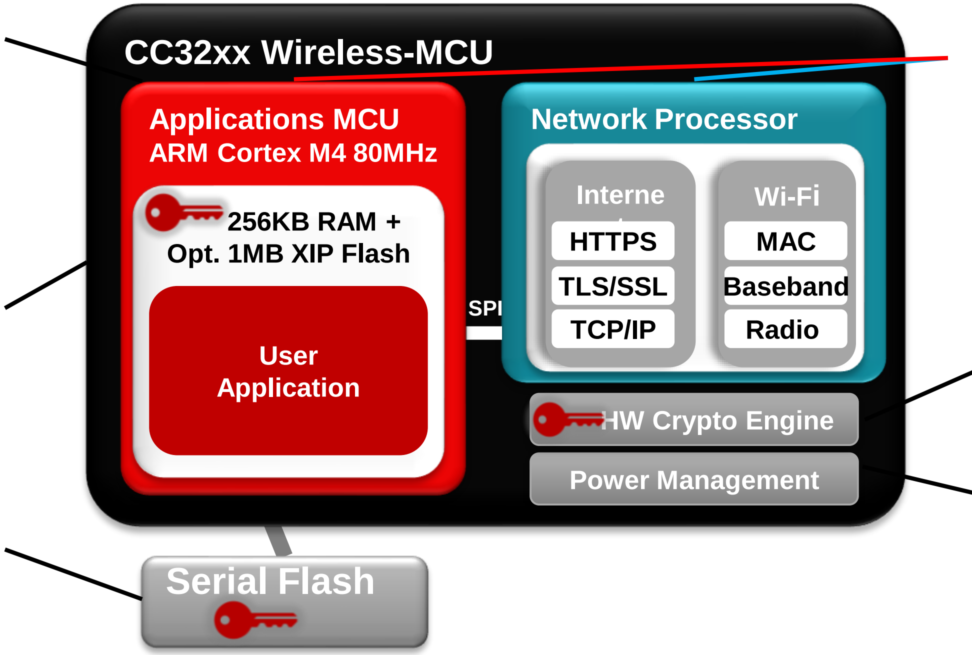
```
{
    "Version": "2012-10-17",
    "Statement": {
        "Effect": "Allow",
        "Action": [
            "iot:CreateJob",
            "signer:DescribeSigningJob"
        ],
        "Resource": "*"
```

SimpleLink Wi-Fi: Architected for better security

Single chip enclosed architecture for reduced attack surface

Embedded security features reduce need for external secure components

Encrypted File System for Customer IP/data and end user’s data security



2 Separate execution environments: MCU + NWP for enhanced assets isolation and easy application integration

HW crypto engines enable fast TLS secure connection establishment within 200msec

Cryptographic utilities simplify sign & verify operations to validate any new image

Software

- File system security: Encryption, Access control, Authentication, Bundle protection, Software tamper detection, Cloning protection
- Initial secure programming
- Secure Boot

Embedded HW

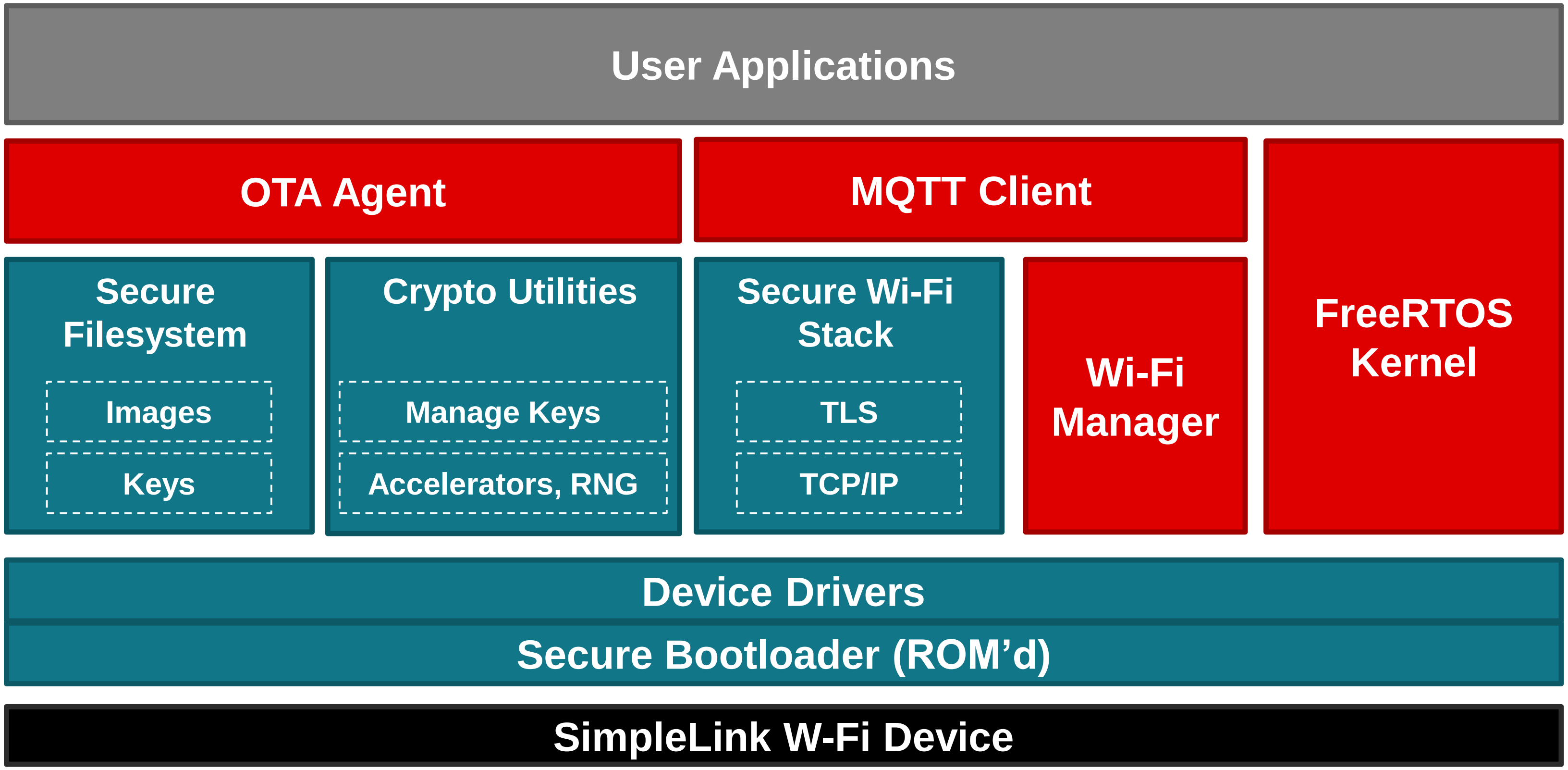
- Hardware Crypto Engine for advanced fast security, including: AES, DES, SHA/MD5, and CRC.
- Device-Unique Key
- Debug Security: JTAG and Debug Ports can be Locked

Networking

- Personal and enterprise security: WPA/WPA2 PSK, WPA2 Enterprise
- Full TCP/IP stack with TLS
- Embedded HTTPS Server
- Unique Device Identity
- Trusted Root-Certificate Catalog

Amazon FreeRTOS integration with SimpleLink SDK

- SimpleLink connected MCUs have a standard SDK across all devices
- The SimpleLink SDK feature extensive run-time libraries that Amazon FreeRTOS leverages in its secure OTA solution



User Applications

OTA Agent

MQTT Client

FreeRTOS Kernel

Secure Filesystem

Images

Keys

Crypto Utilities

Manage Keys

Accelerators, RNG

Secure Wi-Fi Stack

TLS

TCP/IP

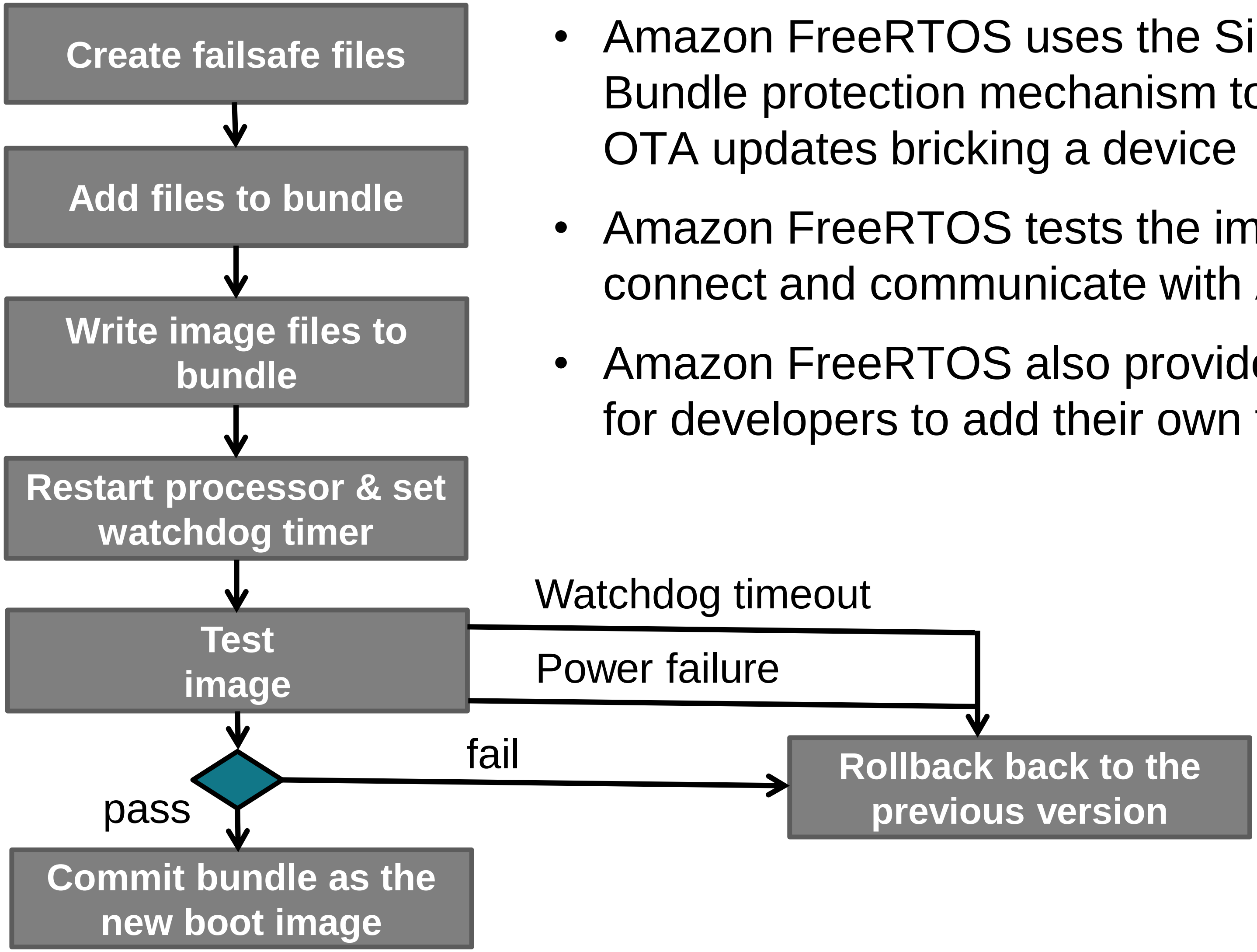
Wi-Fi Manager

Device Drivers

Secure Bootloader (ROM’d)

SimpleLink W-Fi Device

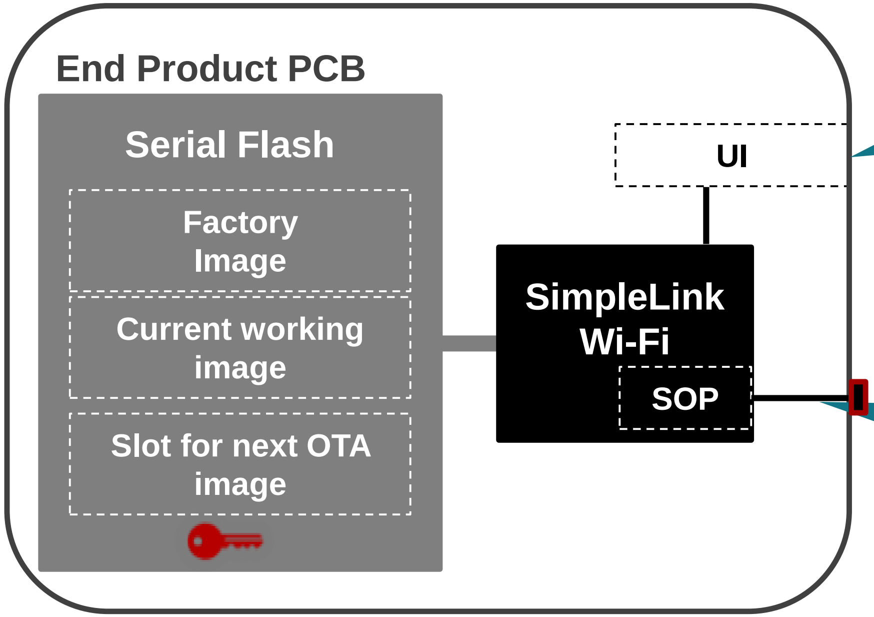
OTA reliability: SimpleLink Bundle Protection


Create failsafe files
Add files to bundle
Write image files to bundle
Restart processor & set watchdog timer
Test image
Watchdog timeout
Power failure
fail
pass
Rollback back to the previous version
Commit bundle as the new boot image

- Amazon FreeRTOS uses the SimpleLink Bundle protection mechanism to avoid OTA updates bricking a device
- Amazon FreeRTOS tests the image can connect and communicate with AWS/IoT
- Amazon FreeRTOS also provides a hook for developers to add their own testing

OTA Reliability: Factory Image Recovery

- As an additional recovery mechanism to use for malfunctioning or bricked devices, SimpleLink Wi-Fi devices include a capability to restore to a device to a factory image



If the application MCU is still running and the IoT device has an UI, it can provide an option to reset the network processor to a factory image combined with the most recent service pack downloaded

If the IoT Device is totally unresponsive, both the application MCU and network processor can be reset to a factory image via the SOP (Sense-On-Power) pins.

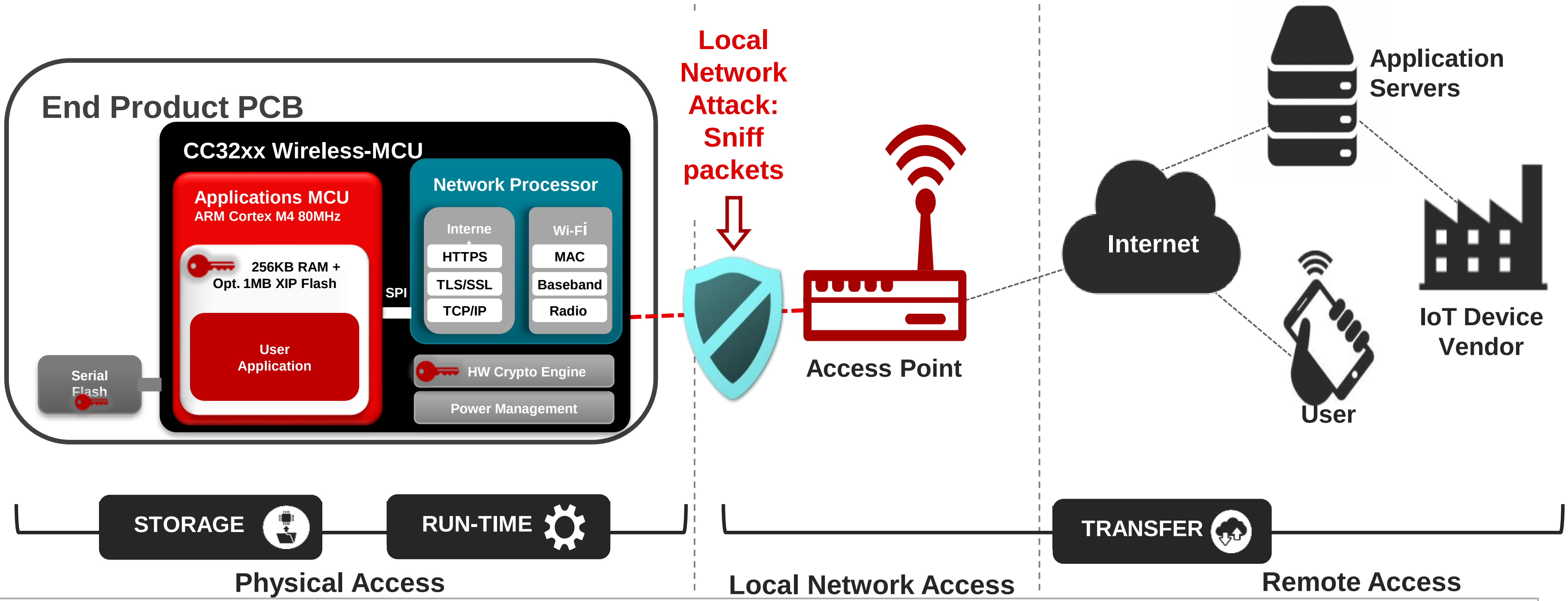
OTA Update Security Measures

Hardware Crypto Engines

Local network with WPA/WPA2 encryption by the HW crypto engines, offloading the host

Personal and Enterprise Wi-Fi Security

OTA Security
The SimpleLink device opens a secured Wi-Fi connection to the Access-Point



OTA Update Security Measures

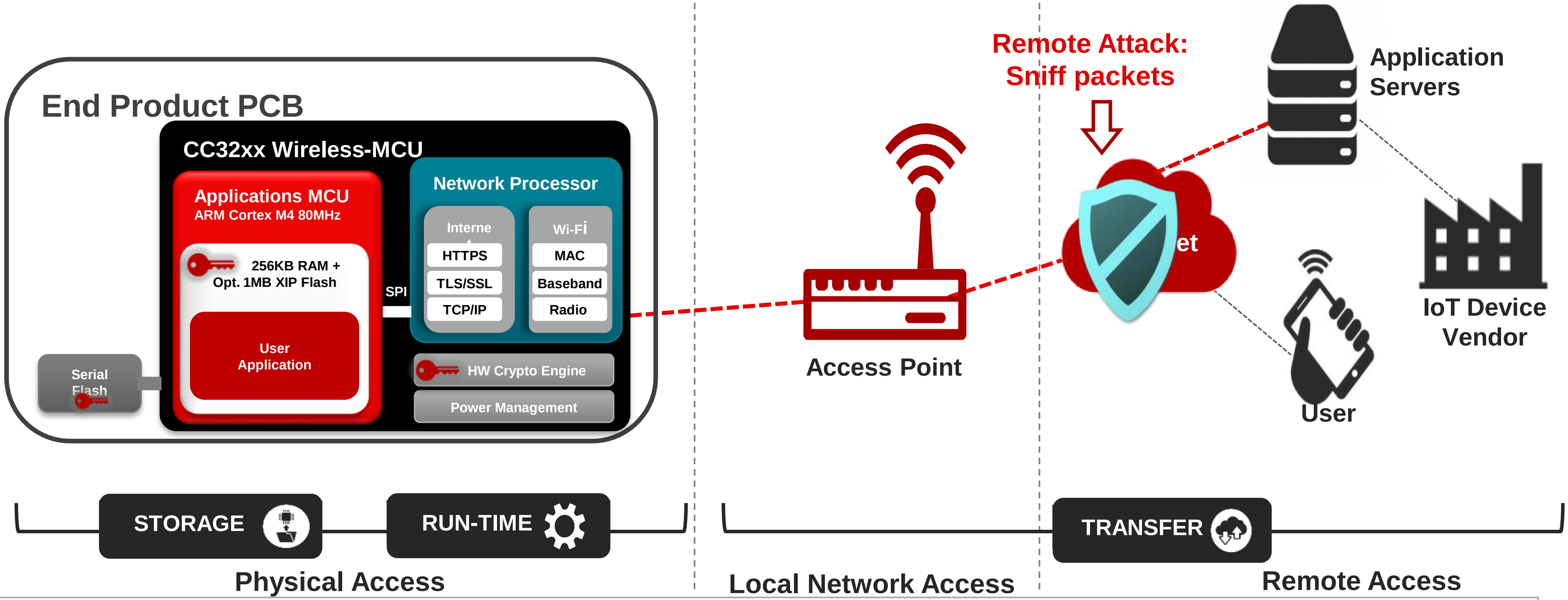
Hardware Crypto Engines

HW encryption engines establish a fast TLS/SSL internet connection within <200mSec

Secure Sockets (TLS\SSL)

TLS/SSL are in the NWP, within the BSD Socket layer

OTA Security
The SimpleLink device has a secured TLS connection to the AWS IoT service.



Remote Attack: Sniff packets

End Product PCB

CC32xx Wireless-MCU

Applications MCU
ARM Cortex M4 80MHz

256KB RAM +
Opt. 1MB XIP Flash

User Application

SPI

Network Processor

Internet: HTTPS, TLS/SSL, TCP/IP

Wi-Fi: MAC, Baseband, Radio

HW Crypto Engine

Power Management

Serial Flash

Access Point

Internet

Application Servers

IoT Device Vendor

User

STORAGE

RUN-TIME

TRANSFER

Physical Access

Local Network Access

Remote Access

OTA Update Security Measures

Hardware Crypto Engines

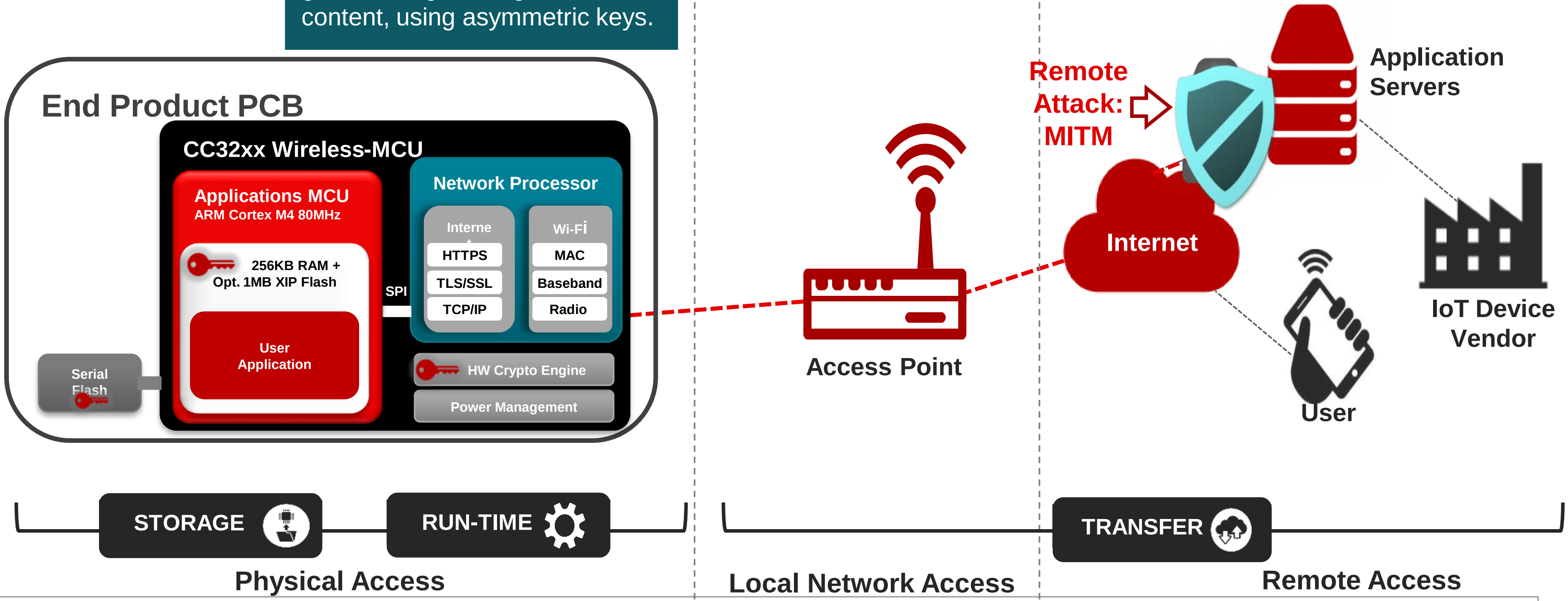
Trusted Root-Certificate Catalog

Built-in secure mechanism to ensure a CA is trusted as root of certificate chain for TLS purpose and file signing.

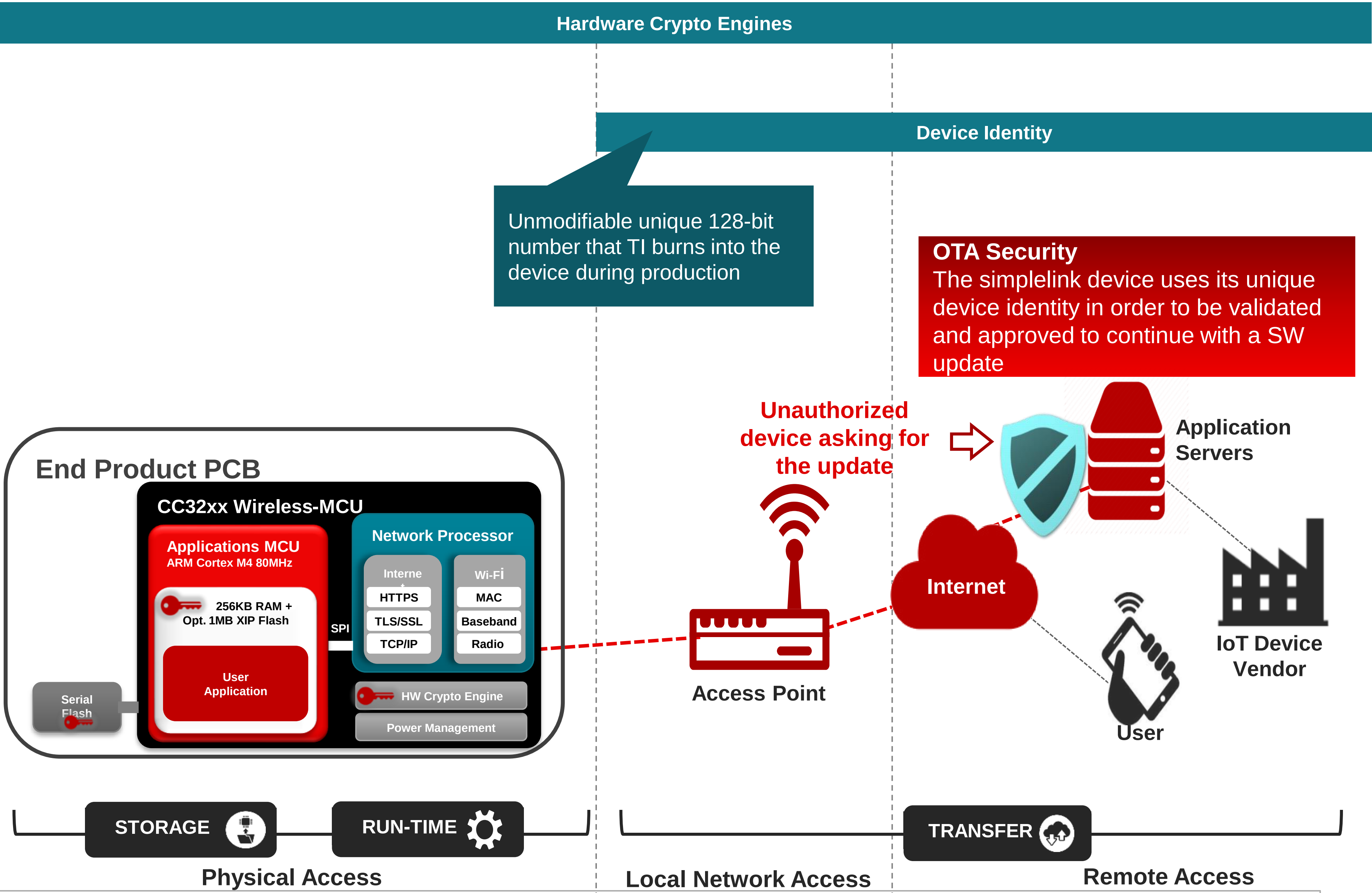
TI Root of Trust Public Key

HW-based mechanism that allows authenticating TI as the genuine origin of a given content, using asymmetric keys.

OTA Security
During the TLS connection the server is authenticated to the SimpleLink's trusted root certificate catalog.



OTA Update Security Measures



Hardware Crypto Engines

Device Identity

Unmodifiable unique 128-bit number that TI burns into the device during production

OTA Security
The simplelink device uses its unique device identity in order to be validated and approved to continue with a SW update

Unauthorized device asking for the update

OTA Update Security Measures

Hardware Crypto Engines

File System Security

Unique Key - Cloning Protection

The file system is readable only by the device which first booted the image

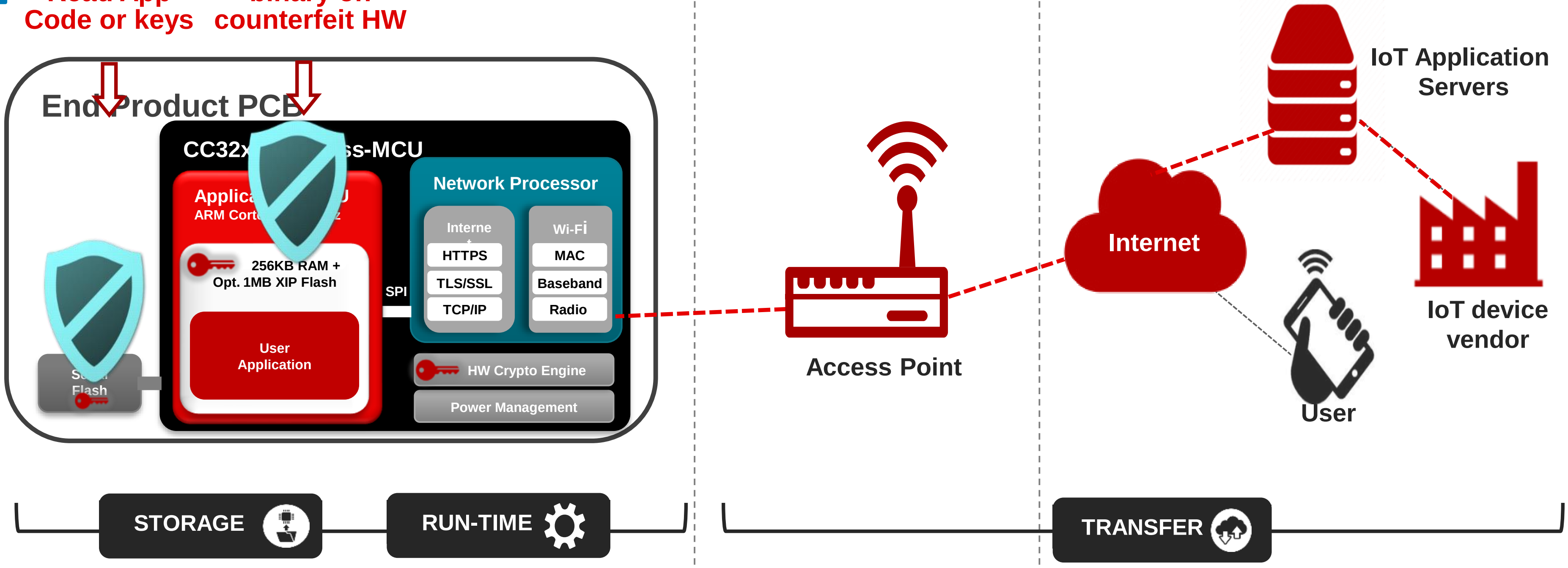
File Encryption

File system is encrypted so image cannot be read without the key

Physical Access Attack: Read App Code or keys

Physical Access Attack: Copy and run binary on counterfeit HW

OTA Security
The updated files access control and authenticity are validated and then stored on the Simplelink’s secured file system



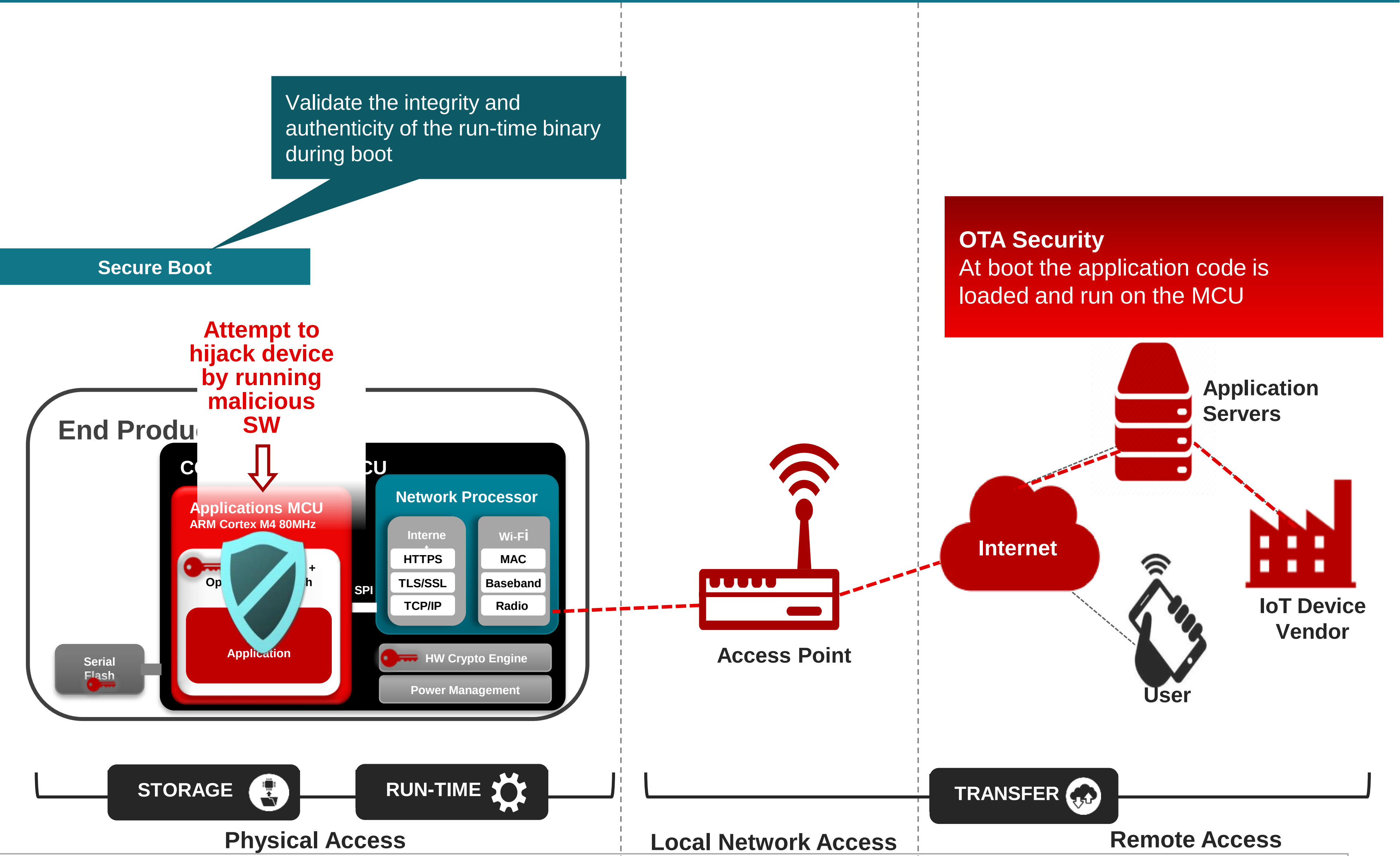
Physical Access

Local Network Access

Remote Access

OTA Update Security Measures

Hardware Crypto Engines



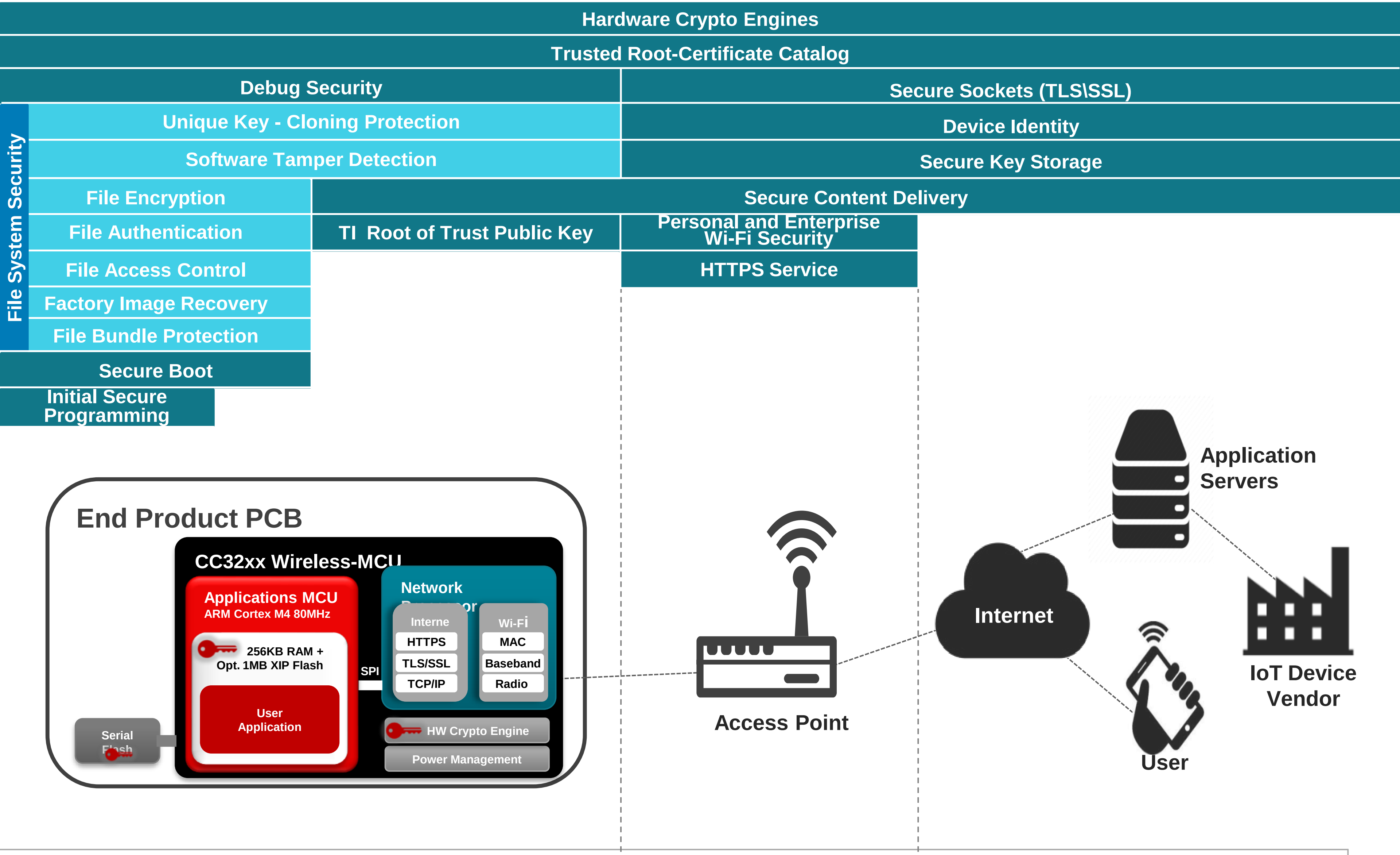
Validate the integrity and authenticity of the run-time binary during boot

Secure Boot

OTA Security
At boot the application code is loaded and run on the MCU

Attempt to hijack device by running malicious SW

SimpleLink Wi-Fi: Multi Layer Security Measures



Hardware Crypto Engines

Trusted Root-Certificate Catalog

Debug Security

Secure Sockets (TLS\SSL)

File System Security

Unique Key - Cloning Protection

Device Identity

Software Tamper Detection

Secure Key Storage

File Encryption

Secure Content Delivery

File Authentication

TI Root of Trust Public Key

Personal and Enterprise Wi-Fi Security

File Access Control

HTTPS Service

Factory Image Recovery

File Bundle Protection

Secure Boot

Initial Secure Programming

Resources

For more information

SimpleLink Wi-Fi devices and tools

- http://www.ti.com/wireless-connectivity/simplelink-solutions/wi-fi/overview/overview.html

Getting started with a CC3220SF Launchpad

- http://www.ti.com/tool/CC3220SF-LAUNCHXL

Review CC3220 technical documents

- http://www.ti.com/product/CC3220/technicaldocuments

Amazon FreeRTOS and Secure OTA

- https://aws.amazon.com/freertos/
- https://docs.aws.amazon.com/freertos/latest/userguide/freertos-ota-dev.html

AWS IoT

- https://aws.amazon.com/iot/

Summary

OTA Updates are a critical capability for an IoT device but introduce the potential for security and reliability risks

CODE

Amazon offers an end-to-end secure OTA solution based on AWS IoT cloud services and Amazon FreeRTOS embedded software

Amazon FreeRTOS is integrated with the SimpleLink SDK, enabling it to leverage SimpleLink Wi-Fi’s built-in OTA security and reliability features