lease

IoT Security-as-a-Service

SARA-R4 / SARA-R5

Application Note

Abstract:
Technical data sheet describing the IoT Security-as-a-Service value proposition for u-blox cellular module series SARA-R4 and SARA-R5.

UBX-20013561 - R06
C1-Public

Document information

Title	**IoT Security-as-a-Service**	
Subtitle	SARA-R4 / SARA-R5	
Document type	Application Note	
Document number	UBX-20013561	
Revision and date	R06	05-11-2020
Disclosure restriction	C1-Public	

Product status	**Corresponding content status**	
Functional Sample	Draft	For functional testing. Revised and supplementary data will be published later.
In development / Prototype	Objective specification	Target values. Revised and supplementary data will be published later.
Engineering sample	Advance information	Data based on early testing. Revised and supplementary data will be published later.
Initial production	Early production information	Data from product verification. Revised and supplementary data may be published later.
Mass production / End of life	Production information	Document contains the final product specification.

This document applies to the following products:

Product name	
SARA-R4 series	"63" / "73" /"83B" product versions
SARA-R5 series	All product versions

Contents

1 Introduction

1.1 Important note

⚠ To be read before reviewing any other part of this document

The main aspect of this document is to detail the exciting opportunities that customers will have to manage and organize the services and firmware on their own devices. However, this functionality cannot be utilized if the ownership of each device has not been correctly claimed by the customer.

Ownership can only be achieved by sealing a valid DeviceProfileUID into the customer's devices. DeviceProfileUID can be autonomously generated accessing to the personal account in the u-blox Thingstream service management console. Moreover, in order to be authorized to use the IoT Security-as-a-Service APIs you need to generate the access key and secret through the management console.

☞ Before reading this document, look at the Getting started guide to have an overview about all the initial steps required

The ownership process is described in more detail in section 4 below.

1.2 Scope

This document describes what is defined by the term "Security" and how it is implemented in u-blox cellular modules. In the document, "security services" indicates IoT Security-as-a-Service solutions.

Section 2 provides an overview of security and its strengths and details about foundation security as the base for all security services.

Section 3 provides details about the u-blox services APIs.

Section 4 describes claim ownership process.

Section 5 describes Design security.

Section 6 describes End-to-End security.

Section 7 describes Zero Touch Provisioning (ZTP).

2 Security

2.1 Overview

For today's cloud-based information technology environment, it is vital to secure all data from unauthorized or fraudulent access. For IoT devices the security of data is vital to protect both businesses and the individual user / person.

For example:

- In connected retail a POS terminal must **protect revenue flow from fraud** by:
  - Securely controlling access to the payment terminal.
  - By providing payment data to authorized parties only.
- In asset tracking the **data must be authenticated to the correct device** to ensure the integrity of the business process and its control.
- In order to **protect recurring service revenues,** smart devices in buildings must ensure that only authorized technicians can remotely access and troubleshoot building management functions.

IoT devices connect physical objects to provide data traffic and access to networks – however the physical objects (i.e. medical devices, controls, utility meters, vehicles, etc.) and the network of things must also be secured. A weak element in IoT security (also known as a defect or vulnerability) may ultimately also become a safety issue.

The u-blox device security implementation is designed to entirely remove these weak elements and prevent the unauthorized or fraudulent access to the underlying data.

The following definitions will help in understanding the fundamentals of security:

- **Integrity** ensures that pieces of data have not been altered from a reference or controlled version.
- **Authentication** ensures that a given entity (with which the user is interacting) is the expected one.
- **Authenticity** is a special type of integrity, where the reference or controlled version is defined as exactly the state of the data when it was under the control of a specific entity.
- **Confidentiality** means that no unauthorized access to the data is allowed (that is, encryption or cryptography will be used).

2.2 Foundations of u-blox security

The strengths of the u-blox security service include the following:

- **Unique device identity:** An immutable chip ID together with a robust root of trust provide the foundational security.
- **Secure boot sequence and update processes**: Only authenticated and authorized firmware and updates can run on the device.
- **Hardware-backed crypto functions**: A secure client library generates the keys and cryptographic functions to securely connect to the cloud.
- **Root of trust-based authentication**: Using the protected root of trust and unique session keys ensures the integrity and confidentiality of both the communications and the data-at-rest (i.e. inactive data that is stored physically in any digital form).

The following features maintain the integrity of the device over its entire lifecycle.

2.2.1 Secure boot

Secure boot maintains the integrity of the code running on the module to ensure the device only runs trusted software issued by an authorized manufacturer.

Because the authenticity and integrity of the software is secured, the module is suitable to be used in mission critical solutions and enables highly secured devices.

2.2.2 Secure updates

Secure updates performed via FOTA or uFOTA (see the FW update application note [5]) allow the customer's chosen FOTA platform to remotely and securely update the module's firmware. Updates are signed by u-blox and verified before being applied. The resulting updated firmware is then authenticated in the module via the secure boot process.

uFOTA is a comprehensive end-to-end u-blox FOTA service that allows customers control of the process for remotely updating the module's firmware "over-the-air". This process utilizes the additional security provided between the module and the service via PSK provisioning.

uFOTA enables the updating of the module firmware at no extra data overhead and cost of implementing such services and processes, since they are implemented by u-blox.

☞ Customer permission is always required before any updates are performed.

2.2.3 Secure production

Secure production is undertaken with a significant emphasis on security, using well designed processes and methods. The root of trust (RoT) is securely provisioned with personalization data (using several keys). The personalization data is delivered using multiple layers of encryption to protect it during the end-to-end process. Each layer of encryption is only retrieved at the correct stage in the process, with the final layer only being retrieved within the module RoT itself.

As mentioned, the benefit for customers is that the module can be used in mission critical solutions and enables highly secured devices.

☞ u-blox provisions secrets into each SARA-R4 module during the production process.

SARA-R5 products integrate a secure element in which secrets are provisioned by the secure element chip manufacturer before the u-blox production process.

2.2.4 Root of trust

The **root of trust** (RoT) can always be trusted within a cryptographic system by providing a comprehensive set of advanced security tools including:

- The secure execution of user applications.
- Tamper detection and protection.
- Secure storage and handling of keys and security assets.
- Resistance to side-channel attacks.

In SARA-R4 products the RoT is implemented in a **trusted execution environment** (TEE) and is a critical component of the system.

A TEE is a secure area inside the main processor (trusted OS area), which is physically separated from the rich OS (rich execution environment, REE) where applications are running. It protects the confidentiality and integrity of the code and the data loaded into the TEE. It provides an excellent level of robustness that is sufficient for the majority of IoT applications. A RoT implemented in the TEE provides a better level of robustness compared to classic systems, which only implement security in the REE.

In SARA-R5 products the RoT is integrated in a secure element (SE).

A secure element is a dedicated microprocessor chip which stores sensitive data and runs secure applications. It acts as a vault, protecting what's inside the SE (applications and data) from malware attacks that are typical in the host (i.e., the device operating system). This secure element is Common Criteria certified EAL5+ and it allows to have eUICC on SARA-R5 since the GSMA and mobile network operators require at least EAL4 to host an eSIM.

☞ SARA-R4 "63B", "73B","83B" product versions implement the RoT in the TEE.

☞ SARA-R5 products implement the RoT in the SE.

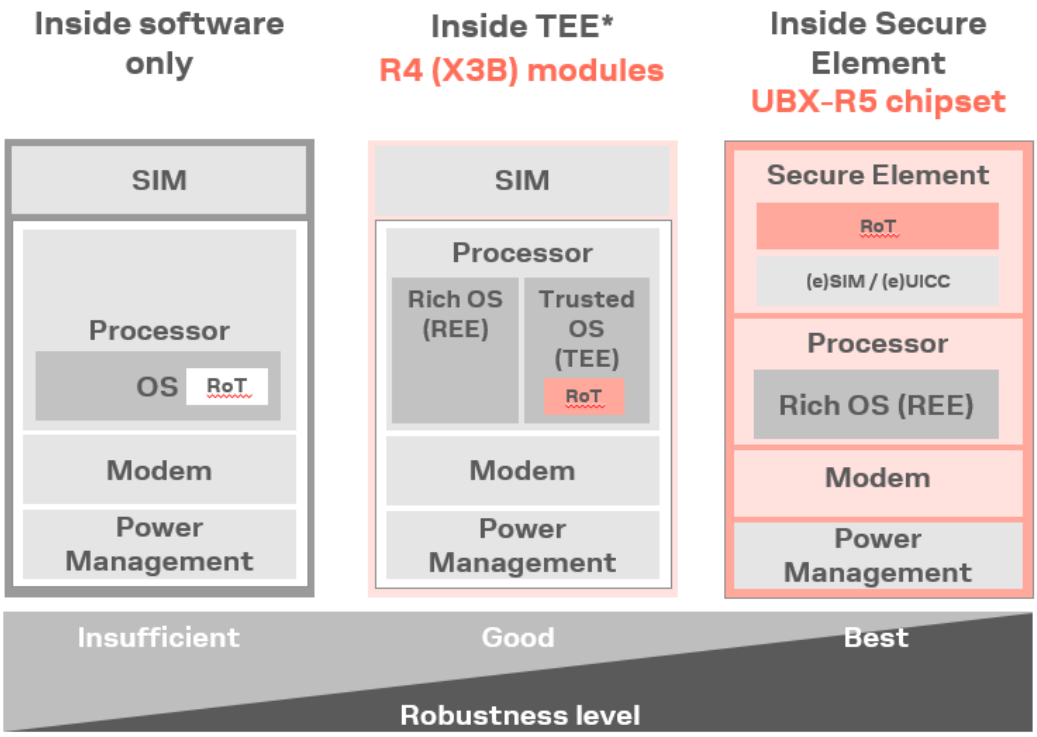


Figure 1: Security robustness levels

The IoT device is secured using the following steps:

- **Provision trust – insert the root of trust at production:** An immutable chip ID and the hardware-based root of trust inserted during the production process provide the foundational security and a unique device identity.
- **Leverage trust – derive the trusted keys:** Secure libraries and hardware-supported crypto functions allow the generation of keys that securely connect the device to the cloud.
- **Guarantee trust – use secure keys to secure any function:** Secure keys ensure the authenticity, integrity, and confidentiality to maintain control of the device and the data.

3 Services APIs

The u-blox IoT Security-as-a-Service APIs provide cloud services to customers from where they can access and manage the security features and processes for their devices, along with any other functionality described in this document.

The REST APIs are defined and fully documented in the separate on-line documentation available at "https://api.services.u-blox.com". The swagger (YAML) specification file can be downloaded from the same webpage.

If not yet done, we strongly recommend users to read the Getting started guide

3.1 REST APIs security

The APIs are secured using an API key and secret which can be generated on the u-blox Thingstream services portal. The secret is used to generate an authorization header, which is used to authorize the requests made to u-blox (see sections 6.1.1 and 6.2.3).

For further details on how to generate the authorization header, see the swagger documentation at https://api.services.u-blox.com.

3.2 Accessing the REST APIs

To manage the IoT Security-as-a-Service, customers must first subscribe to an account for the u-blox Thingstream, which is the service and account management platform for IoT Security-as-a-Service. You can select between

- **Basic account:** an IoT Security-as-a-Service free-of-charge account restricted to up to ten active devices
- **Enterprise or Pro account:** for more than 10 active devices; this is required to enable the commercial version and to access to advanced features

Once access to the APIs has been granted, the customer will be able to view and manage the IoT Security-as-a-Service attributes on their devices.

The APIs can be used to manage the following:

- Claim of ownership of individual devices as part of the bootstrap process (see section 4)
- Service provisioning and IoT Security-as-a-Service management functionality (see section 4.5) including the management of:
  - Individual devices
  - The security services that are enabled / disabled on each device
  - The device profiles used to identify devices and owners
  - The process to organize global updates of multiple devices to enable or disable the security services on them

The Sequence diagram in Figure 2 shows the API access process including:

- Customer onboarding
- Service account creation
- API key and secret retrieval
- Refresh Auth token
- Call APIs

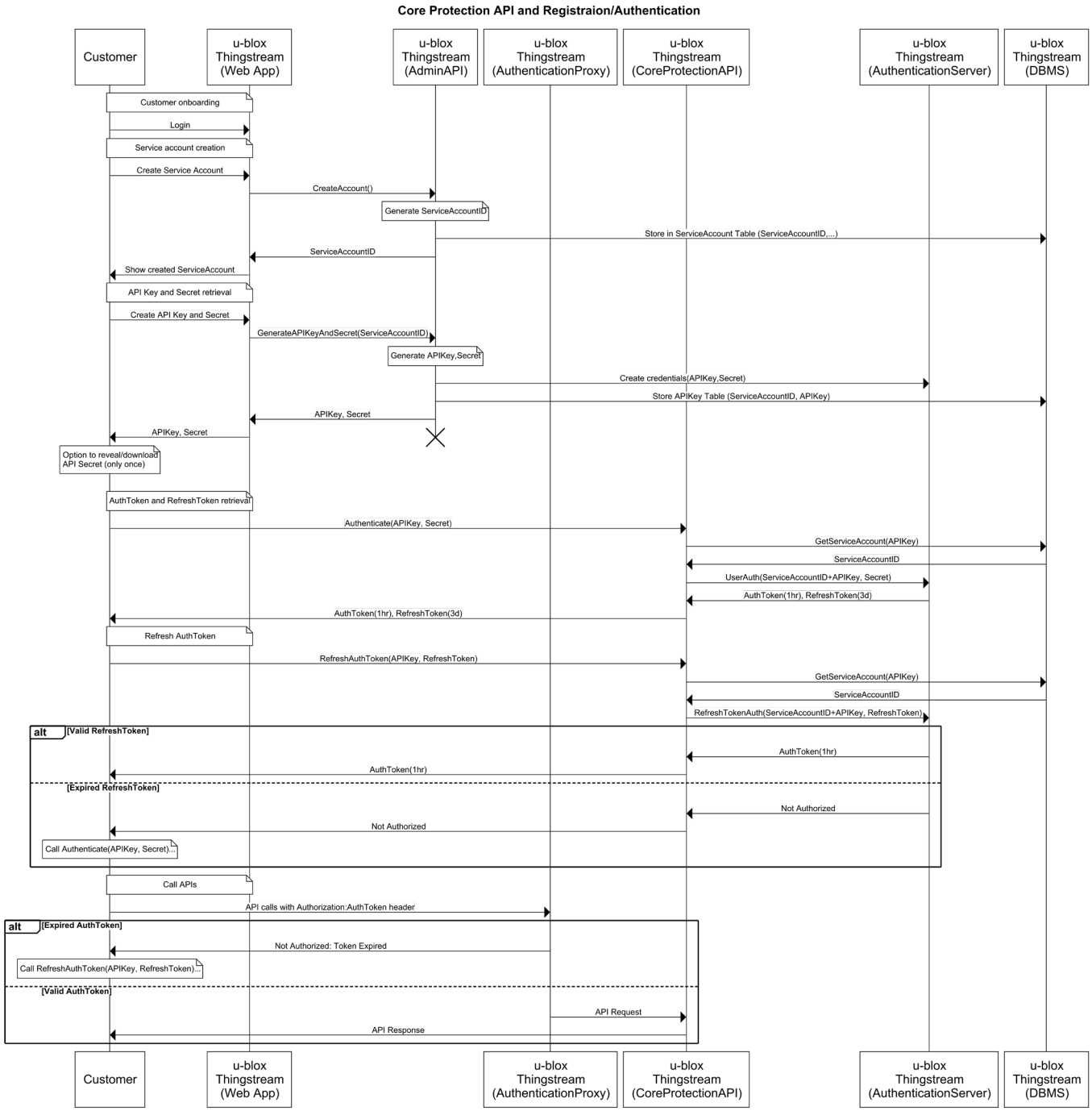


Figure 2: API access processes

3.3 How to access the u-blox IoT Security-as-a-Service when using a private network

To ensure the security services processes will work, customers using a private network (private APN) must first check that their devices can reach the u-blox security service.

In particular, check that the module is able to connect to the domain icpp.services.u-blox.com.

If the module cannot reach the domain icpp.services.u-blox.com, the IPv4/IPv6 addresses may need to be whitelisted on the private APN server in order to allow the connection to be made.

4 Claim ownership

4.1 Automatic enrollment

Ownership can only be achieved by sealing a valid DeviceProfileUID into the customer's devices. Once customers have a service account, they can use the APIs to request a DeviceProfileUID and seal it in their devices accordingly.

Secrets are provisioned into each module during the production process (the secrets are unique to each module and are identified by the **RoT public unique identifier** - RoTPublicUID).

To claim ownership of individual devices, customers must first create a DeviceProfileUID using the u-blox Thingstream Service management console.

The **device profile unique identifier** – DeviceProfileUID is equivalent to a model number and can be used to identify a group of similar devices that need to have the same set of Security features enabled at bootstrap.

Customers must then store the DeviceProfileUID into each device within the same group (normally this is all the devices with the same type number). This is completed (either in their host firmware, e.g. on device startup, or on their production line) by using the AT+USECDEVINFO AT command, along with their own **device serial number** (this unique number for the device will be defined by the customer).

☞ With the AT command you seal the DeviceProfileUID and the device serial number into the RoT; they cannot be changed once they have been set – any subsequent calls to this AT command are ignored. Please be careful on sealing the correct DeviceProfileUID generated through the u-blox Thingstream platform.

Command	Response	Description
`AT+USECDEVINFO="DeviceProfileUID","serial"`	`OK`	Seal the DeviceProfileUID and the device serial number into the module.

☞ Please note you can just do sealing procedure (via AT+USECDEVINFO) once and any future retry will be ignored by the device.

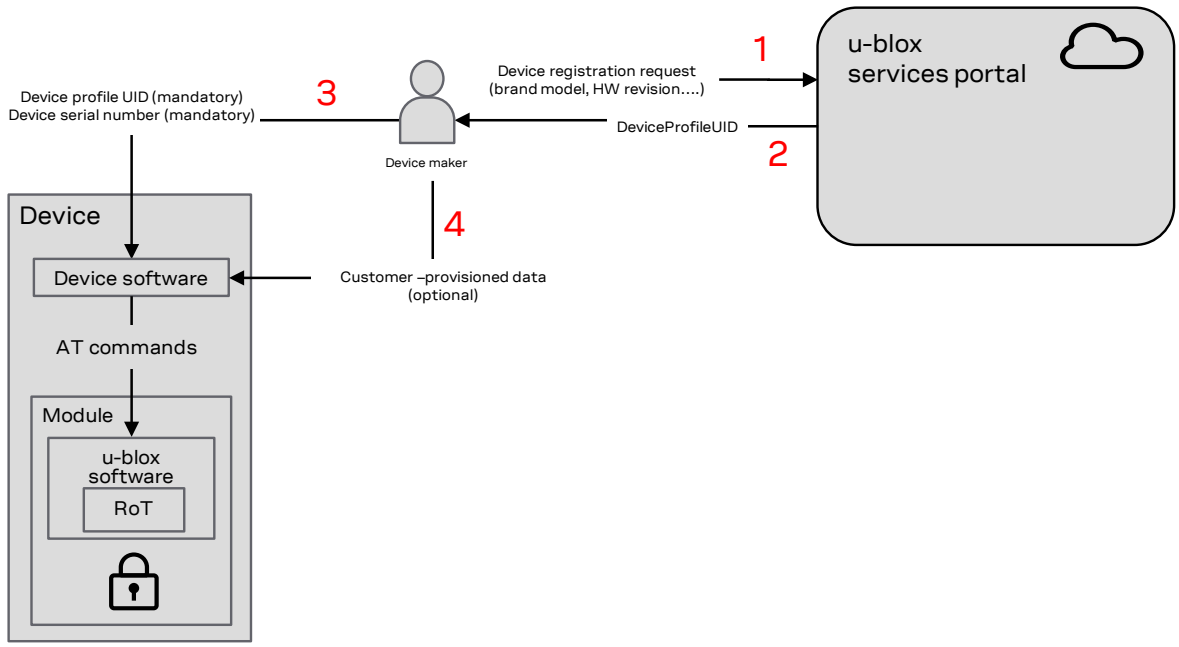


Figure 3: Process to set DeviceProfileUID and device serial number

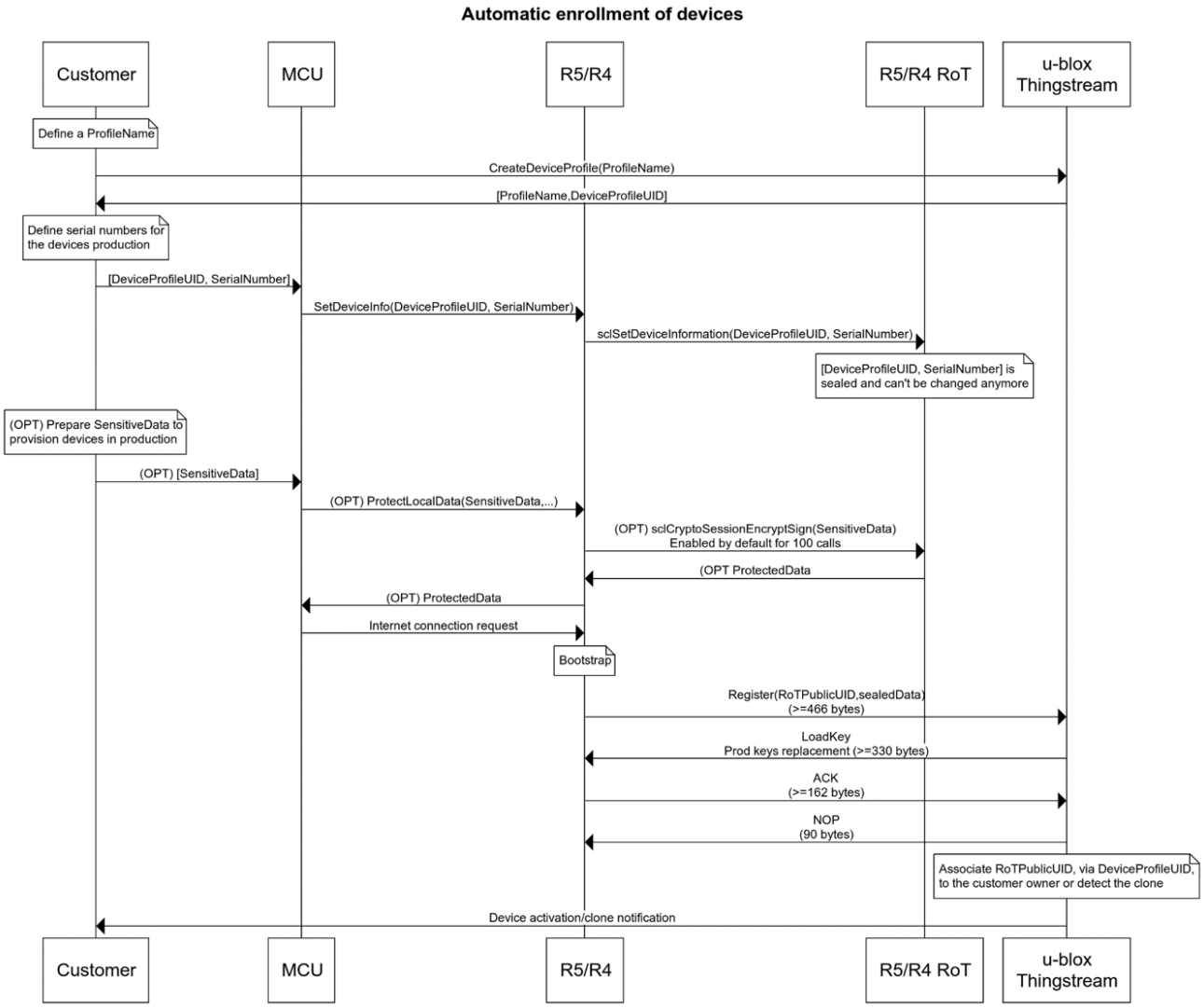


Figure 4: Automatic enrollment of device process

Device profile unique identifiers (DeviceProfileUID) shall be used by the customer to "label" and claim ownership of each device:

- Assign the DeviceProfileUID to the module using the +USECDEVINFO AT command
- Bootstrap the device in order to link it to the matching DeviceProfileUID created by u-blox

Once a device bootstraps, the system will recognize the DeviceProfileUID and assign ownership of the device to the correct customer account (the company). It is then possible to configure the device further using the functionality available in the u-blox services APIs.

The basic process for the customer to claim ownership of a device is:

1. Create the Device Profile UID.
2. Seal each DeviceProfileUID into the correct device(s).
3. Connect each device to the Internet.
4. Wait for each device to register to security services (monitor the status via AT+USECDEVINFO? query).
5. The device should now be assigned into customer's account and the device registration date should be set.

☞ Customers can enable IoT Security-as-a-Service on device(s) when they bootstrap. This option removes the need to create similar campaigns once the bootstrap has been successful and means the required IoT Security-as-a-Service features are immediately available following a successful bootstrap.

4.1.1 Change the ownership

You have the possibility to change the ownership of a single device or a group of devices. There are procedures in the u-blox back-end to handle it for you. Just write to services support (thingstream-support@u-blox.com) and please provide the following information:

- DeviceProfileUID of the device(s) that the ownership should be changed
- Current owner thingstream domain name
- Future owner thingstream domain name

4.2 Bootstrap and device assignment to the owner procedure

1. The module bootstraps to the u-blox security server (icpp.services.u-blox.com) when the actual device first connects to the internet. The bootstrap process happens only once; if subsequent power cycles occur, then the device is recognized as already being bootstrapped.
2. The process replaces the factory-provisioned secrets and adds the necessary keys to enable the relevant features/services.
3. During bootstrap the device becomes associated with its registered owner (via the DeviceProfileUID that was created) and any cloned devices are rejected.
4. The customer now has ownership of the device.

⚠ During the initial bootstrap it is recommended that the application does not try to reset or power cycle the module until the process is completed successfully. The time needed to conclude the process is strictly dependent on the RAT being used. If the bootstrap process is interrupted before completion, the process will re-start from the beginning.

The bootstrap process requires 4 individual communication phases over which at least 1048 bytes are transferred. The maximum amount of data that can be transferred will vary and can depend on:

1. Whether “Feature authorizations” data must be sent.
2. Whether retransmissions must be done because an original attempt failed.
3. Whether Internet Protocol version 4 (IPv4) or version 6 (IPv6) is being used.

The +USECDEVINFO can be called to confirm that the bootstrap attempt has either not yet finished (that is, the current attempt was not successful, and another attempt will be tried) or the bootstrap process has been successful.

Command	Description
AT+USECDEVINFO?	Check bootstrap status.

The response to the AT+USECDEVINFO? Query has the following meaning:

Command	Response	Description
AT+USECDEVINFO?	+USECDEVINFO: 0,0,0	The module is not able to reach the u-blox security service. No bootstrap can be performed. Check that data connection is available and a suitable APN has been set.
	+USECDEVINFO: 1,0,1	The module is registered to the u-blox security service and bootstrap has started. Device has not been sealed with a DeviceProfileUID yet.
	+USECDEVINFO: 1,1,1 OK	The module is registered to the u-blox security service and bootstrap is complete.

If the bootstrap process is still in progress (that is, it has not finished or been successful or an error condition has occurred), then the AT command will return an error.

☞ In SARA-R4 products, if the bootstrap process is still in progress, AT+USECDEVINFO? Will block until the operation is complete.

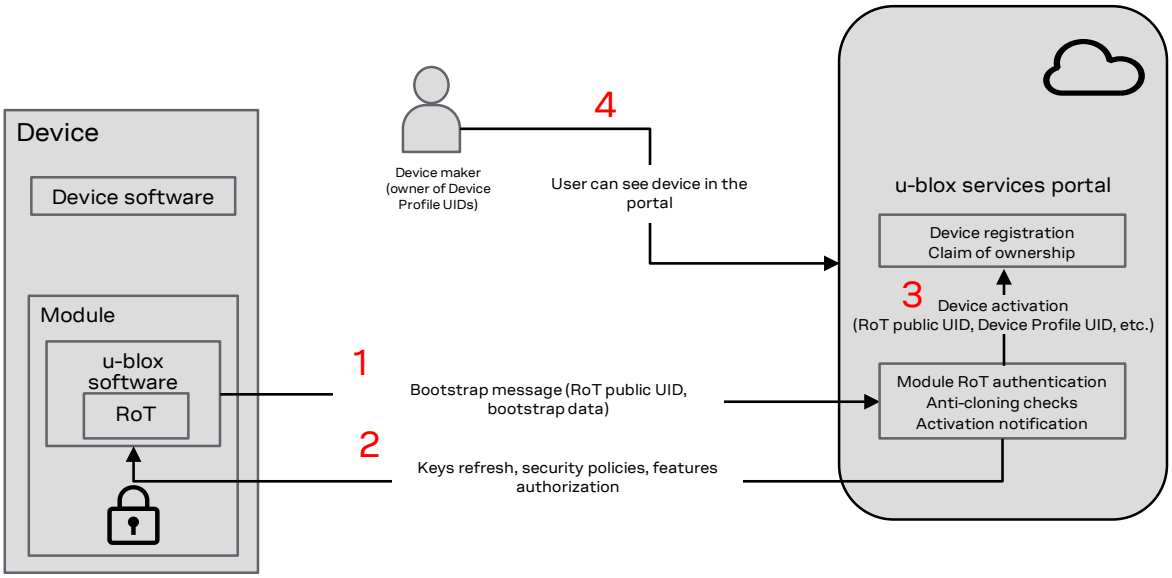


Figure 5: Device bootstrap process

4.3 Two stage bootstraps

In some circumstances the bootstrapping of one or more devices may need to be completed in two stages (two-stage bootstrap).

This is the scenario when the bootstrap happens when the DeviceProfileUID has not already been sealed in the device. The device is registered but cannot be assigned to the correct customer.

When, at a later stage, the DeviceProfileUID is sealed in the device, it communicates with the u-blox server and it is therefore assigned to the correct customer. The customer can then manage the device using the u-blox Thingstream Management console or the APIs.

4.4 Security heartbeat

Once a device has successfully bootstrapped, it will continue to call the u-blox security service on a regular basis: this is known as a "security heartbeat".

By default, the security heartbeat occurs automatically once a week. It is possible, though, to trigger a security heartbeat from the module by using the AT+USECCONN command:

Command	Response	Description
AT+USECCONN	OK	Trigger a security heartbeat to the u-blox security service.

☞ To prevent flooding the server with security heartbeat messages, if the command is issued within 5 minutes of the last sent security heartbeat, the request will be rejected, and an error result code will be returned.

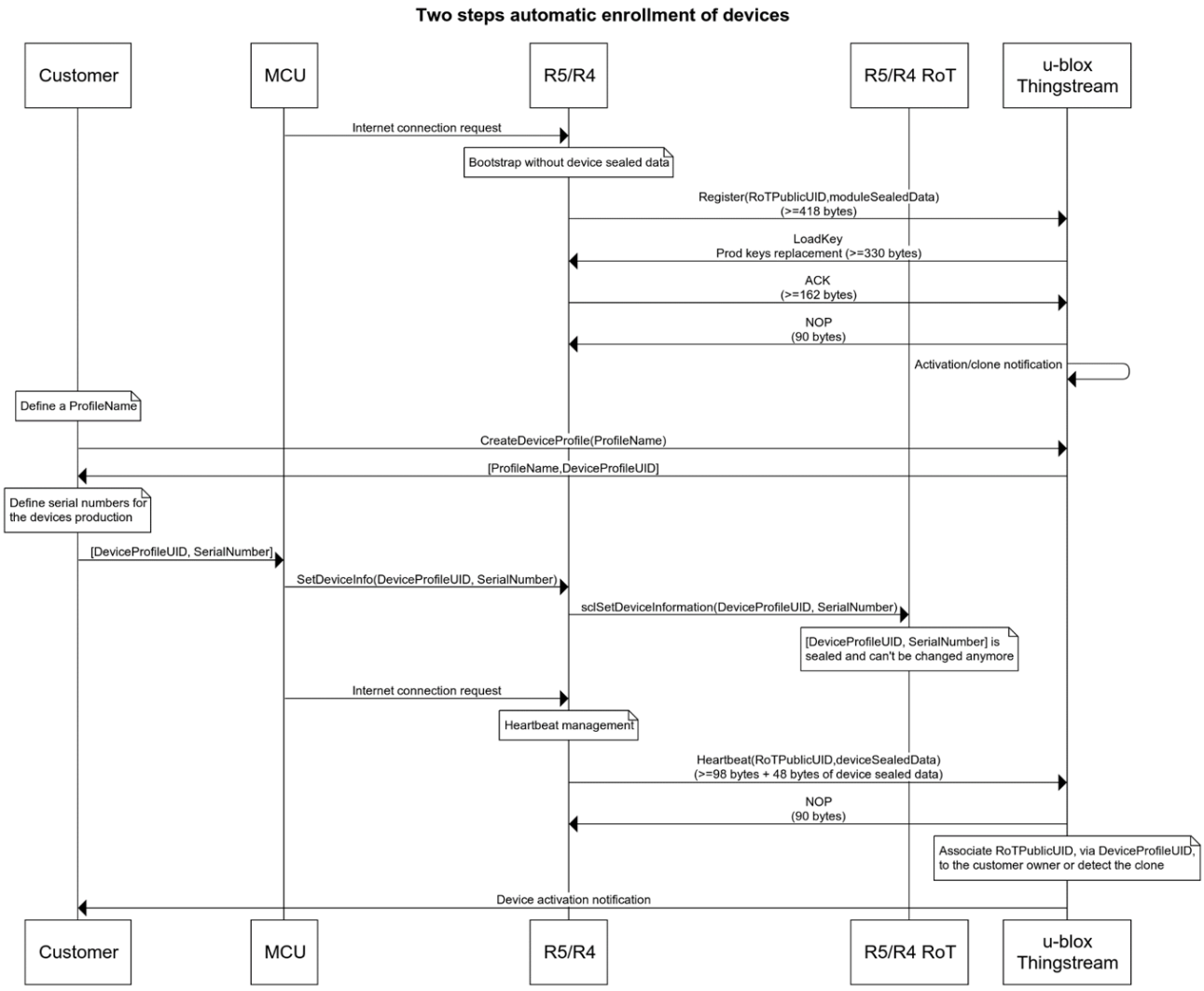


Figure 6: Enrollment of devices with security heartbeat

4.4.1.1 Security heartbeats on SARA-R4

To prevent flooding the server with "security heartbeats", if the command is issued within 5 minutes of the last sent "security heartbeat", the request will be rejected, and an error result code will be returned. The system time is used for measuring elapsed time. When a "security heartbeat" is sent, the system time is stored in NVM, therefore the value is persistent to power cycles. When an attempt to send a "security heartbeat" occurs, the previous send time is checked against the current system time, to see if the elapsed time is valid.

4.4.1.2 Security heartbeats on SARA-R5

- The "security heartbeat" message operation is required to update the status of the security.
- The "security heartbeat" message operation is for security reasons required to be an atomic message operation using a blocking send/receive cycle.
- The blocking send/receive cycle can execute up to 5 minutes (before timeout and abort) in case of network issues.
- The blocking send/receive cycle can block (up to 5 minutes) the execution of the command (affected commands listed below) which triggered the "security heartbeat" message operation.
- The "security heartbeat" message operation before executing the blocking send/receive cycle verifies if the "security heartbeat" message shall be sent immediately due to security reasons.
- The "security heartbeat" message operation before executing the blocking send/receive cycle verifies if the "security heartbeat" message shall be sent immediately due to server configured time period elapsed.

To prevent flooding the server with "security heartbeats", if the command is issued within 24 hours of the last sent "security heartbeat", the request will be rejected, and an error result code will be returned. The system time is used for measuring elapsed time. When a "security heartbeat" is sent, the system time is stored in NVM; therefore, the value is persistent to power cycles. When an attempt to send a "security heartbeat" occurs, the previous send time is checked against the current system time, to see if the elapsed time is valid.

4.5 Feature provisioning

Customers can activate/deactivate a feature in two ways:

- At device profile level: when the device profile is created using the Management Console. In this case all devices that makes the bootstrap with that DeviceProfileUID, will get activated the selected features. Be aware that if you change the Device profile definition at a later stage (i.e. deactivating a feature previously enabled), this change will be applicable only to the devices that make bootstrap from that time.
- At device level: on each **active** device you can activate/deactivate a feature at any time using the Management console or the APIs

Activation/deactivation on the device happens at the next Security Heartbeat event after that you have applied the new setting. You can monitor the status both from the API and the Management console.

You can always trigger the Security Heartbeat as described in section 4.4

Feature provisioning is applicable to:

- Local Data Protection
- Local Chip-to-Chip Security
- Zero Touch Provisioning

4.5.1 Service provisioning

Symmetric KMS (PSK) and E2E data protection services are automatically provisioned during the bootstrap process when the customer selects a price plan that includes also these services (Developer, Daily, Flex, Freedom) during device Profile definition; therefore the services can be used IMMEDIATELY after the bootstrap. In case the customer, during device profile creation, selects a price plan that does not include the above services, they can be anyway activated in a later stage by going in the Management console and associate a different price plan to the Security thing. As for feature activation, the services will be enabled at the next Security Heartbeat.

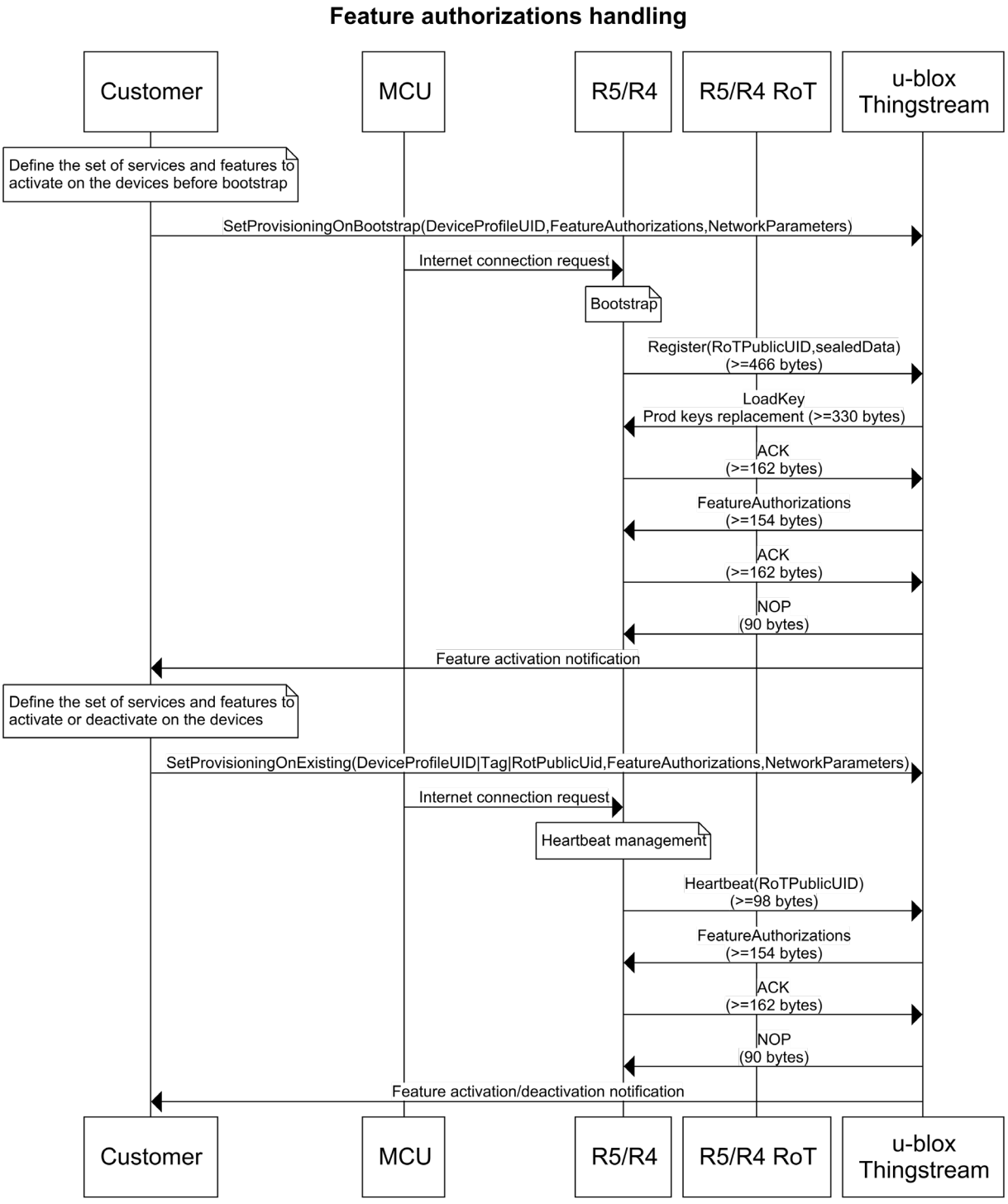


Figure 7: Handling process for feature authorizations

4.6 Anti-cloning detection and rejection

The anti-cloning detection system detects devices that appear to be using the same RoT and will allow only the first device that communicates to bootstrap with the service. All subsequent calls from any other devices using the same RoT (cloned devices) are automatically blocked by the service.

5 Design security

Because the privacy of the data is paramount, the u-blox data security processes guarantee the integrity of both the local data on the device and the data transmitted to the cloud by ensuring that the identity and authenticity of the data and the device's firmware is maintained.

In this section we focus on the security of the data which does not need to go over the air. There are two main questions/concerns here: First, can I secure my host-to-module interface? (Confidentiality and integrity for AT commands on the serial interface) And second How can I secure my data-at-rest? "local C2C security" is the service to address the first concern and "local data protection" is our solution for the second question.

Features	Secure communications (D)TLS	Local data protection	Local Chip-to-chip security
SARA-R4 "63", "73","83B"	•	•	
SARA-R5 "00"	•	•	•

Services	E2E Symmetric KMS	E2E data protection
SARA-R4 "63", "73","83B"	•	•
SARA-R5 "00"	•	•

5.1 Local C2C (Chip-to-Chip) Security

Chip-to-chip is a mechanism to establish a secure channel between the MCU and the module (SARA-R5) to protect AT-Commands and data. It is a unique cryptographic pairing/binding solution, between the MCU of the hosting device and the module, providing confidentiality, integrity and authenticity for their communication channel.

AT-Commands, parameters and command outputs as well as all data are encrypted using an encryption key previously generated in production by RoT and sent to MCU.

The pairing is done once at device production and RoT-derived keys can be used on each session. The key provided must be stored safely by the MCU. Re-pairing can be authorized via REST API if required.

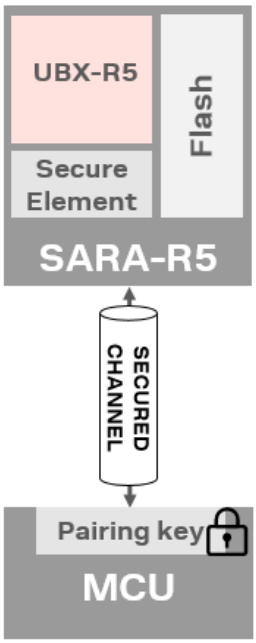


Figure 8: Chip-to-chip secure pairing

Local C2C security steps:

- **“C2C key pairing”** (The MCU obtains the encryption key through a process called)
- **“Open secure session”** (The MCU starts a secure session through a process called)
- **“Close secure session”** (The MCU closes a secure session through a process called)
- **“C2C rekeying/repairing”** (The MCU request a new encryption key through a process called)

Local C2C AT commands related to each step

AT Commands	Purpose
+USECC2C=0, <te_secret>	C2C key pairing
+USECC2C=1, <te_secret>	Open secure session
+USECC2C=2	Close current secure session
+USECC2C=3	Rekeying of the current secure session

Please note:

- Chip-to-chip security service can support Multi sessions, over different MCUs. The module supports up to 8 different encryption keys distributed among MCU’s.
- C2C encryption exists in two versions.
  - The first version was implemented within the first releases of SARA-R5 00B. Encryption protocol V1 is using a MAC THEN ENCRYPT scheme with the use of SHA256 and AES 128 CBC mode of operation.
  - The second version is intended to be used for all further products. Encryption protocol V2 is using an ENCRYPT then HMAC scheme with the use of HMAC_SHA256_T128 and AES 128 CBC mode of operation.
- The behavior of mentioned processes depends on the bootstrap status. More information will be provided in the following sectors.

5.1.1 C2C encapsulation and encryption protocol

5.1.1.1 C2C binary encapsulation format

C2C frame structure :

SF	SIZE	DATA	CHECKSUM	EF

SF	start flag marks the start of an C2C frame /*size 1 byte*/
SIZE	size of the data in the frame excluding SF, SIZE, CHECKSUM, EF /*size 2 bytes*/
DATA	data in the C2C frame /* variable size - maximum size 2^8 bytes*/
CHECKSUM	checksum of the SIZE and DATA using Frame Check Sequence (FCS) see RFC 1662
EF	end flag marks the end of an C2C frame /* 1 byte */

5.1.1.2 C2C encryption protocol

C2C encryption exists in two versions. The first version was implemented within the first releases of SARA-R5 00B and security issues have been found. The second version resolves the security issues and is intended to be used for all further products.

5.1.1.2.1 C2C encryption protocol V1

Encryption protocol V1 is using a MAC THEN ENCRYPT scheme with the use of SHA256 and AES 128 CBC mode of operation. The Initialization vector is generated by the Crypto Cell component.

5.1.1.2.1 C2C encryption protocol V2

Encryption protocol V2 uses an ENCRYPT then HMAC scheme with the use of HMAC_SHA256_T128 and AES 128 CBC mode of operation. The Initialization vector is generated by the Crypto Cell component.

The communication process with the C2C encapsulation and encryption through SEND / RECEIVE is presented below.

Send:

1. step GENERATE DATA CHUNKS from the DATA
   - - AT commands - maximum chunk size TBD
   - - File data in raw mode - maximum chunk size TBD
   - - Other data in raw mode - maximum chunk size TBD
2. step ECRYPT DATA CHUNK ENCRYPTED_DATA_CHUNK = DATA_ENCRYPTION (k1, k2, TE_SECRET, DATA_CHUNK)
3. step GENERATE C2C FRAME C2C_FRAME = (0xf9, DATA_CHUNK_SIZE, ENCRYPTED_DATA_CHUNK, 0x0000, 0xf9)
4. step ADD CHECKSUM to the C2C FRAME C2C_FRAME.ADD_CHCK_FCS16(C2C_FRAME)
5. step send the frame using the serial interface

   Repeat STEPS 2. 3. 4. 5. for every chunk in CHUNKS

Receive:

1. step retrieve a C2C_FRAME by observing the 0xf9 frame start and frame end flag
2. step verify the CHECKSUM of the retrieved C2C_FRAME using the CHCK_FCS16
3. step extract the ENCRYPTED_DATA_CHUNK from the C2C_FRAME
4. step decrypt the ENCRYPTED_DATA_CHUNK to get the DATA_CHUNK
5. step add the DATA_CHUNK to a DATA_CHUNKS_BUFFER
6. interpret the DATA_CHUNKS_BUFFER

5.1.2 Local C2C key pairing

Is the process of obtaining the keys by MCU. In this section we will take a look at the process, command s and the functional requirements of local C2C key pairing.

5.1.2.1 Local C2C key paring process:

Each MCU (if more than one) has its own encryption key obtained like so:

- Each MCU (if more than one) should generates a <te_secret> and send it to module via "**+USECC2C=0, <te_secret>"** AT command.
- Module generates the encryption key generation material:
  - <slave_secret> random number
  - < module_secret> chip_id
- Module retrieves the terminal device name of the AT terminal executing the command.
- Module stores the <te_secret, at_dev_name, slave_secret, module_secret> record where:
  - <te_secret, at_dev_name > are record identifiers
  - <slave_secret, module_secret> are used to generate the encryption key
- Module reports to the MCU the generated encryption key

5.1.2.2 Local C2C Key paring commands:

- AT+USECC2C = 0, <TE_SECRET>
  - <TE_SECRET> parameter used to identify the key generation material. Not used as material for key generation
- Up to 8 different TE_SECRET/TERMINAL_DEVICE_NAME combinations.
- C2C Key Pairing stage available “before” USEC bootstrap.
  - once per TE_SECRET/TERMINAL_DEVICE_NAME combination
  - The command can be executed up to reaching the LocalDPR limit
  - can NOT override an already present TE_SECRET/TERMINAL_DEVICE_NAME combination.
- C2C Key Pairing stage available “after” USEC bootstrap when C2CKeyPairing AFA is enabled.
  - if and only if the LocalC2C AFA is enabled.
  - if and only if the LocalC2CKeyPairing AFA is enabled.
  - can override an already present TE_SECRET/TERMINAL_DEVICE_NAME combination / provides a new C2C key.
- The C2C KeyPairing command creates a record in the DB which enforces the security.
  - Record_structure {<TE_SECRET>,<TERMINAL_DEV_NAME>,<MasterSecret>,<ClientSecret>}
  - MasterSecret and ClientSecret used to create the C2C key using the sclC2cGeneratePSK

5.1.2.3 Local C2C key paring functional requirements:

- The <te_secret, at_dev_name, slave_secret, module_secret> records are stored in a local file (USR/usec/c2c_db) which is encrypted using the local encryption using the key_slot 1.
- **Please note that the process needs to be executed in customer production in a “sanitized environment”, as the C2C encryption key is not encrypted**.
- The customer must execute the key pairing process for all 8 encryption keys to provide the highest level of security.
- The customer must securely store the encryption keys.
- If the encryption key is lost a C2CKeyPairing FeatureAuthorization can be enabled to request a new key pairing process within a non-secure session.

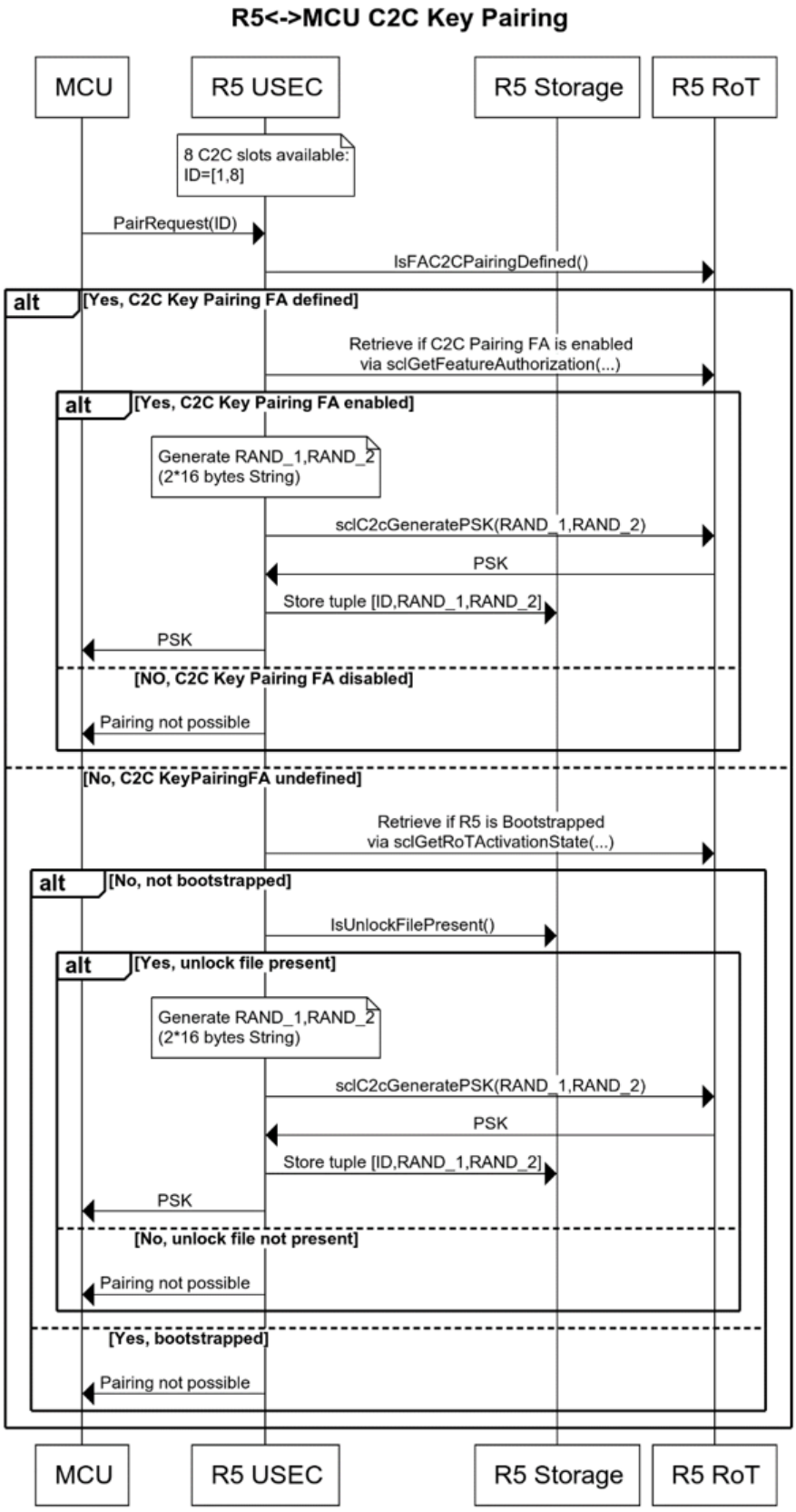


Figure 9: Chip-to-chip key pairing process

Although the guideline is that key pairing should happen in production phase and in a sanitize environment (so before bootstrap) please note that this process can happen in 3 different scenarios:

(Please note that ISEP is a component of the u-blox Thingstream platform.)

- **Before bootstrap (NOT registered with ISEP) and NOT claimed**
  Host MCU → AT+USECC2C=0, <te_secret>
  ← +USECC2C:0,0, <c2c_encryption_key>
  MCU is responsible to store the te_secret and encryption_key.

- **After bootstrap (Registered with ISEP) but NOT claimed**
  Host MCU → AT+USECC2C=0, <te_secret>
  ← NOT_ALLOWED
  MCU can try again after device has been claimed.

- **After bootstrap (Registered with ISEP) and claimed**
  Host MCU → AT+USECC2C=0, <te_secret>
  ← +USECC2C:0,0, <c2c_encryption_key>
  MCU is responsible to store the te_secret and encryption_key.

5.1.3 Local C2C usage (Open secure session)

Open C2C channel:

- AT+USECC2C = 1, <TE_SECRET>
- An C2C channel is opened
- The <TE_SECRET> and <TERMINAL_DEV_NAME> are used to identify the key generation material
- The identified material is used to generate a C2C key which is passed to the MSIO layer which handles the encryption and decryption using the passed key.
- The <TERMINAL_DEV_NAME> is retrieved automatically from the ID of the AT terminal which is being used to execute the c2c open channel command.
- A list of currently opened sessions is maintained. A new record is put on the list when a C2C channel is opened.

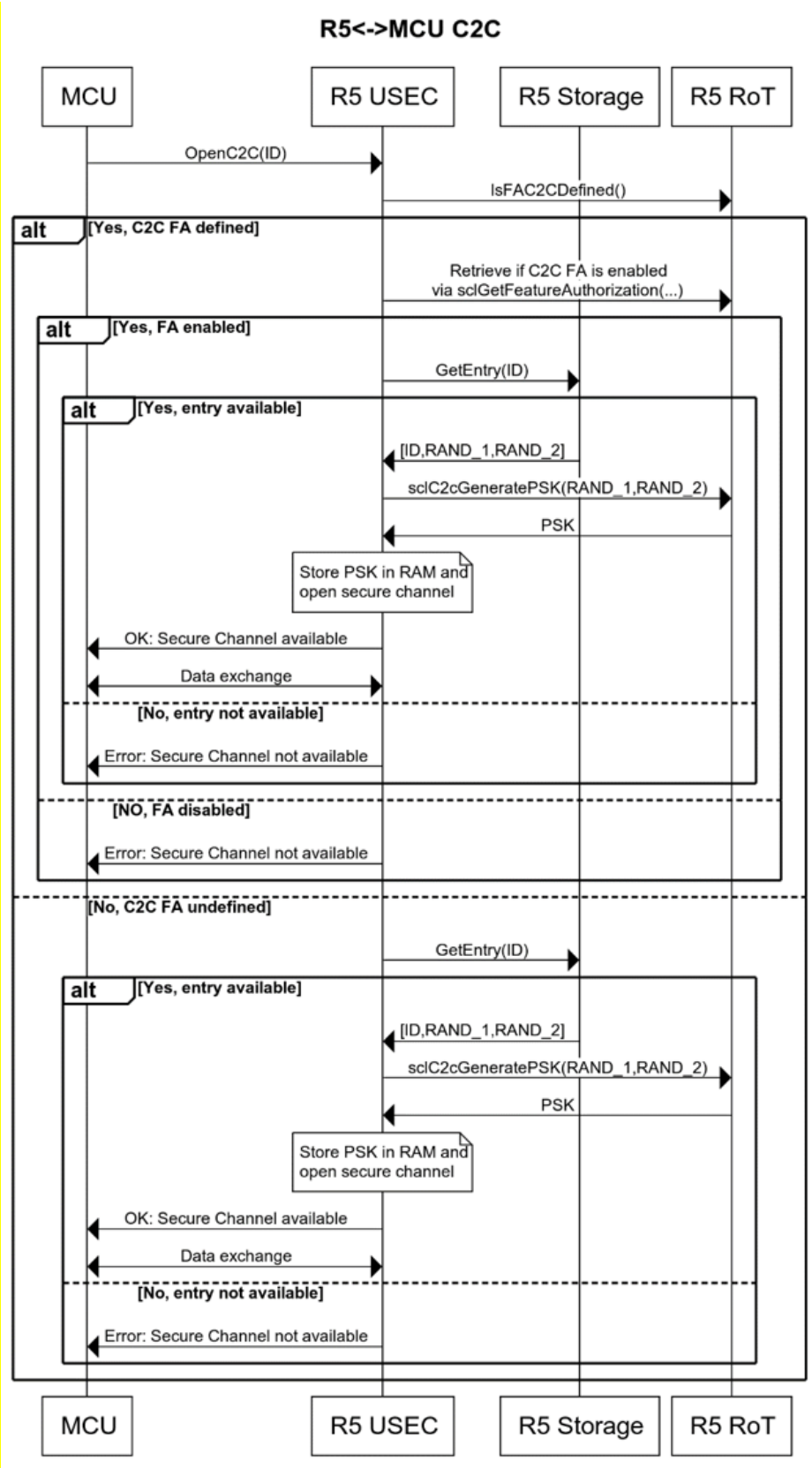


Figure 10: Chip-to-chip pairing

C2C Secure session open

The +USECC2C=1, <te_secret> command opens a secure channel.

There is no guideline or recommendation when to open a secure session. This can happen in three different scenarios.

- **Before bootstrap (NOT registered with ISEP) and NOT claimed**
  Host MCU → AT+USECC2C=1, <te_secret>
  ← PLAIN_TEXT_AT_OK
  → ENCRYPTED_AT_COMMAND
  ← ENCRYPTED_AT_OK
  Having the right c2c_encryption_key (obtained in c2c key pairing phase) now MCU can decrypt the ENCRYPTED_AT_OK message and get the AT_OK.
  You only need to pay attention to the grace (or evaluation) period.
  Grace period < registered to isep.
  Grace period allows execution of localDPR 100 times.
  Grace period allows execution of C2C open (-1)/close (-1) 100 times.

- **After bootstrap (Registered with ISEP) but NOT claimed**
  Host MCU → AT+USECC2C=1, <te_secret>
  ← NOT_ALLOWED
  MCU can try again after device has been claimed.

- **After bootstrap (Registered with ISEP) and claimed**
  Host MCU → AT+USECC2C=1, <te_secret>
  ← PLAIN_TEXT_AT_OK
  → ENCRYPTED_AT_COMMAND
  ← ENCRYPTED_AT_OK
  Having the right c2c_encryption_key now MCU can decrypt the ENCRYPTED_AT_OK message and get the AT_OK.

5.1.4 Local C2C usage (Close secure session)

The +USECC2C=2 command closes a secure channel.

You can close a session at any time (of course if you have already opened one).

(Please note that ISEP is a component of u-blox Thingstream platform.)

- **Before bootstrap (NOT registered with ISEP) and NOT claimed**
  Host MCU → AT+USECC2C=2
  ← ENCRYPTED_AT_OK
  Having the right c2c_encryption_key (obtained in c2c key pairing phase) now MCU can decrypt the ENCRYPTED_AT_OK message and get the AT_OK.

- **After bootstrap (Registered with ISEP) and claimed**
  Host MCU should first retrieve the c2c_encryption_key using the te_secrect. Then using the right key encrypt AT+USECC2C=2
  Host MCU → ENCRYPTED AT COMMAND (AT+USECC2C=2)
  ← ENCRYPTED_AT_OK
  Having the right c2c_encryption_key (obtained in c2c key pairing phase) now MCU can decrypt the ENCRYPTED_AT_OK message and get the AT_OK.

5.1.5 Local C2C Rekeying

The +USECC2C=3 command triggers a rekeying of the current secure session. This can only be called during a secure session.

The re-keying can only be executed within a C2C session. The session used for rekeying is closed.

Host MCU should first retrieve the c2c_encryption_key using the te_secrect. Then using the right key encrypt AT+USECC2C=3
Host MCU → ENCRYPTED AT COMMAND (AT+USECC2C=3)
← ENCRYPTED_AT_OK

Having the right c2c_encryption_key (obtained in c2c key pairing phase) now MCU can decrypt the ENCRYPTED_AT_OK message and get the AT_OK.

5.1.6 Local C2C use-case

The Chip-to-Chip process includes two stages:

1. Key pairing: in this phase new keys are created for a specific secure channel (identified by a HEX string TE_SECRET) between the MT and the TE. Key pairing is available before bootstrap as a trial, for about 50 operations. Once the module has bootstrapped, the key pairing is available when the “LocalC2CKeyPairing” feature is enabled.
2. Usage: in this phase a secure channel, identified by TE_SECRET, is opened or closed between the MT and the TE. C2C usage is available only after bootstrap, when the “LocalC2C” feature is enabled.

R5<->MCU C2C key pairing example:

Command	Response	Description
AT+USECC2C=0,"A0324CFF236F458048656C6C6F6F497D"		Create key pairing for TE_SECRET identifier A0324CFF…6F6F497D. The C2C encryption key used for this TE_SECRET is returned.
…		

R5<->MCU C2C usage example:

Command	Response	Description
AT+USECC2C=1,"A0324CFF236F458048656C6C6F6F497D"	OK	Open secure channel identified by TE_SECRET A0324CFF…6F6F497D.
Enter some other examples here		
AT+USECC2C=2,"A0324CFF236F458048656C6C6F6F497D"	OK	Close secure channel identified by TE_SECRET A0324CFF…6F6F497D.

5.2 Local data protection

Managing symmetric crypto functions via the AT command allows the device to locally encrypt / decrypt and authenticate critical data (e.g. certificates, tokens) on the device itself. The u-blox solution enables customers to store critical data that has been encrypted using the RoT in a non-secure component of the device, for example in the standard device memory.

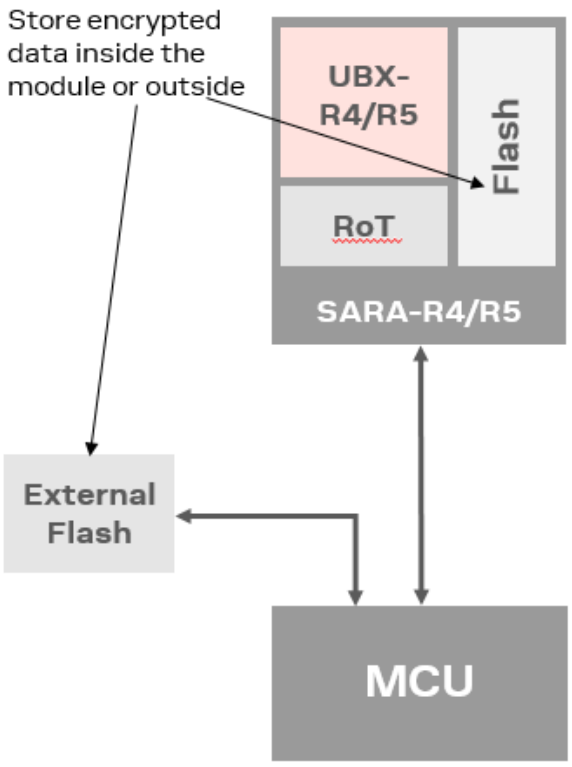


Figure 11: Storing encrypted critical data

The method provides symmetric crypto services via AT command to allow the device to locally encrypt & sign or decrypt & verify data.

Sensitive data used by the device (e.g. device certificates, CA or server certificates for (D)TLS pinning, tokens, (D)TLS session resumption tickets, libraries result of expensive R&D efforts) is securely stored.

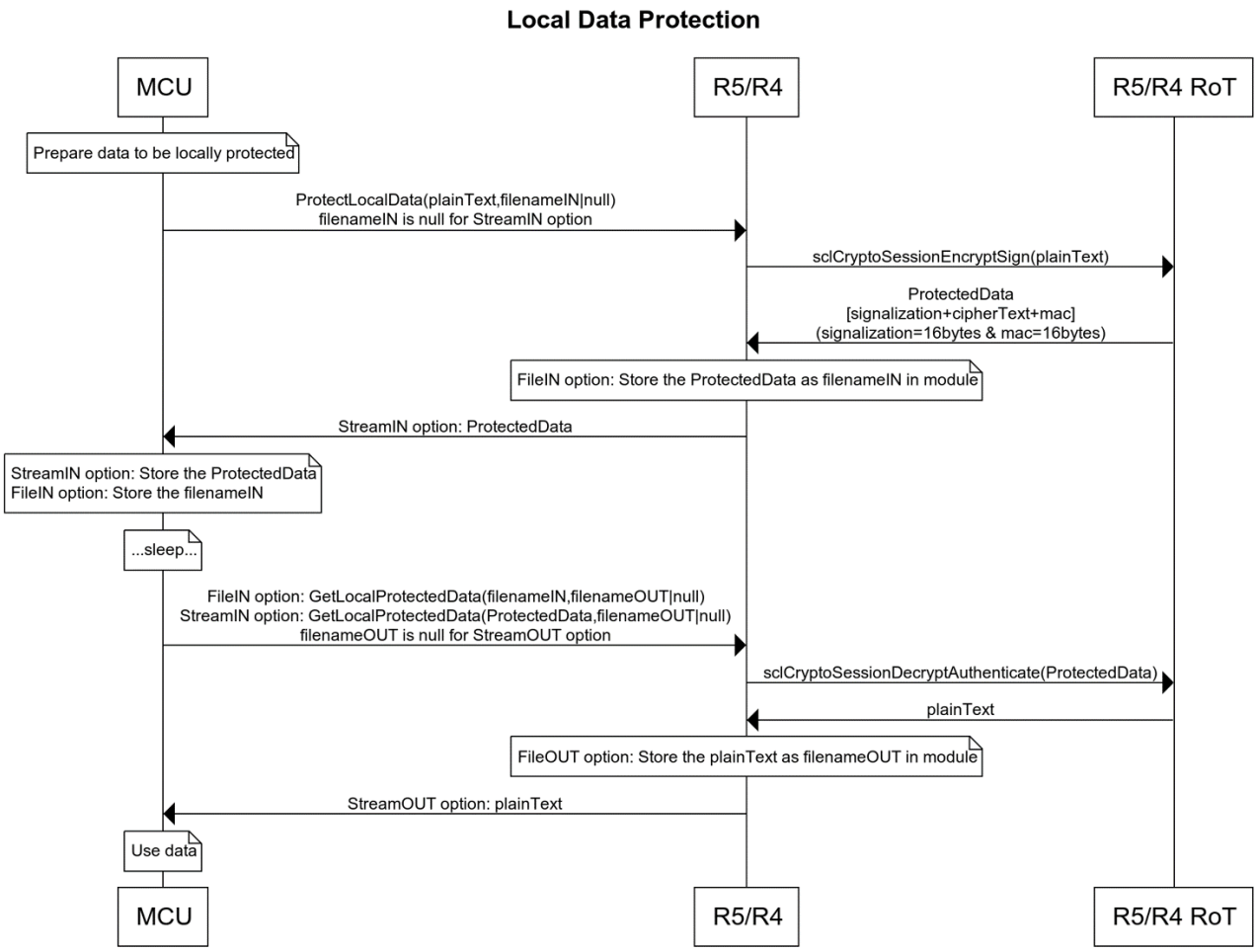


Figure 12: Local data protection process

5.2.1 Use case

The following AT command example encrypts the data string “datatoencrypt” and stores it within the module file system in a file named “ciphertextfile” and decrypts the file “ciphertextfile” that was stored in the module to read and display the text that was previously encrypted.

Command	Response	Description
`AT+USECDATAENC=13,"ciphertextfile" > datatoencrypt`	`OK`	‘ciphertextfile’ is the name of the file in which the encrypted text will be stored – this is a free text name provided by the customer. ‘datatoencrypt’ is the information to be encrypted, for example: a private key, some confidential data, etc.
`AT+USECFILEDEC="ciphertextfile"`	`+USECFILEDEC: 13,"datatoencrypt"` `OK`	‘datatoencrypt’ is a piece of information decrypted (such as private key, confidential data, etc.)

For further details, see the u-blox AT commands manual [2].

6 E2E Security

6.1 E2E Symmetric KMS

PSK cipher suites are ideal for embedded systems that have very limited computing power and only talk to a very small number of servers. With PSK, each side of the connection already has an agreed upon key to use during the TLS handshake. This reduces resource consumption for each session.

Pre-shared keys (PSK) provisioning is a highly scalable method for provisioning and managing session unique PSKs for application layer security. A PSK and a PSKIdentity are generated by the RoT within the module, and used to secure end-to-end communications (e.g. via DTLS) to a customer's cloud service. In particular, during (D)TLS handshake, the module sends the PSKIdentity generated by the RoT inside the ClientKeyExchange message. Once the customer's cloud service gets this information, it will send the PSKIdentity to the u-blox security service (via a REST API) in order to retrieve the same PSK that was used by the module to encrypt the end-to-end communications. The u-blox security service uses the PSKIdentity to re-generate the PSK, without having to communicate with the module.

This delivers the following advantages by:

- Achieving up to eight times reduction in the secure communication data overhead, and therefore reducing cost for data consumption when compared with PKI-based TLS.
- Simplifying both the development and the actual process of obtaining the key by delegating the key management to the u-blox solution.

Customers have the option of either:

- Using their own communication stack: in this scenario, the customer requests a PSK and PSKIdentity pair from the module and uses it to establish a PSK based communication with its own (D)TLS stack. This is described in Option 1 (see section 6.1.1.1).
- Using the communication stacks provided by u-blox: in this scenario the module is configured to automatically establish a PSK based secure connection when trying to connect to a (D)TLS endpoint using any Internet protocol based application provided by the module. This is described in Option 2 (see section 6.1.1.2).

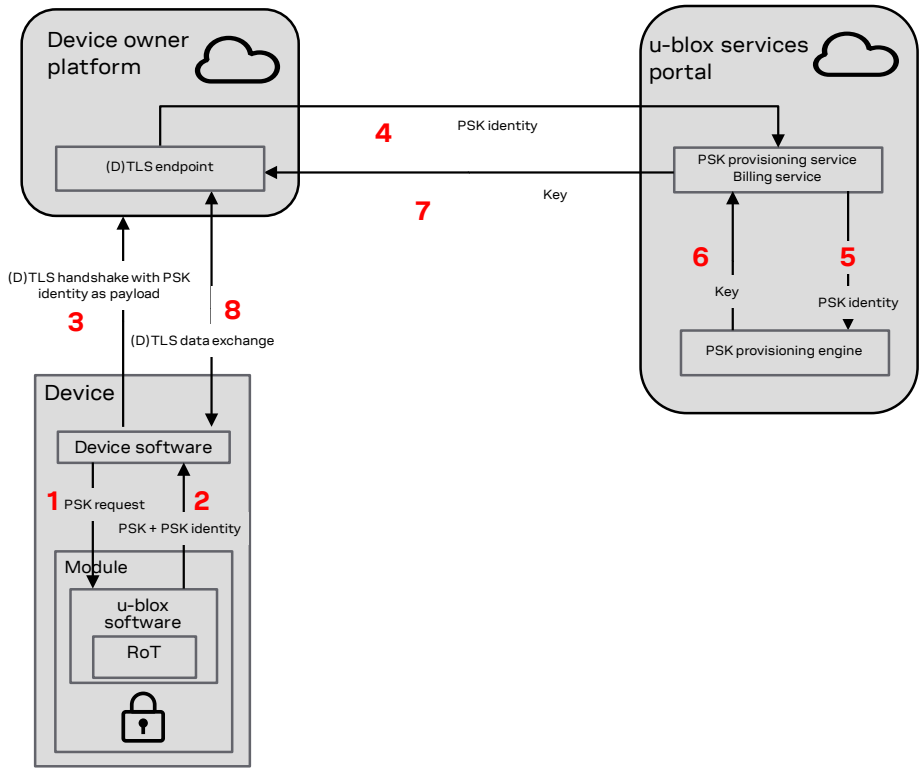


Figure 13: PSK provisioning

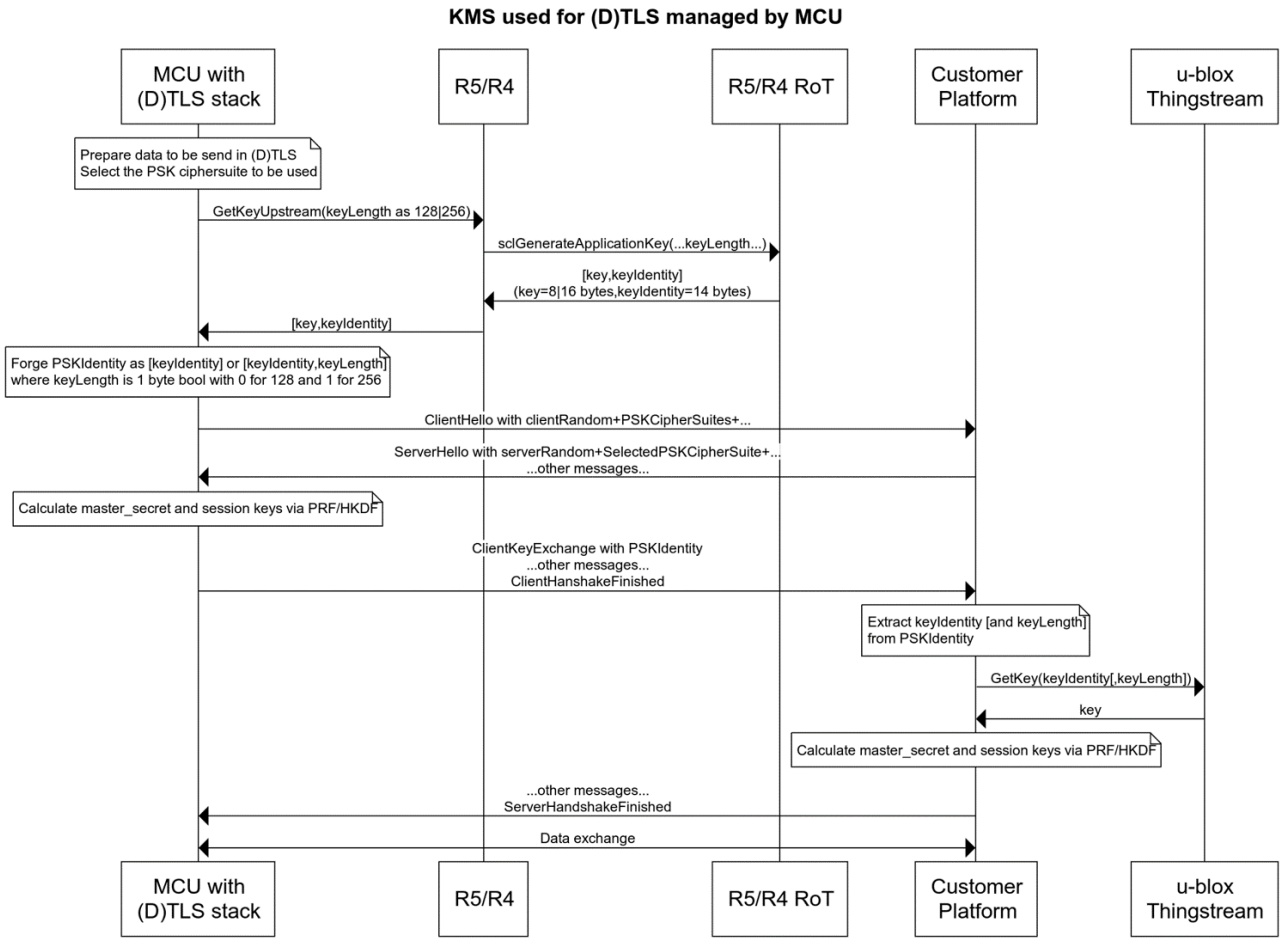


Figure 14: Key management service process managed by MCU

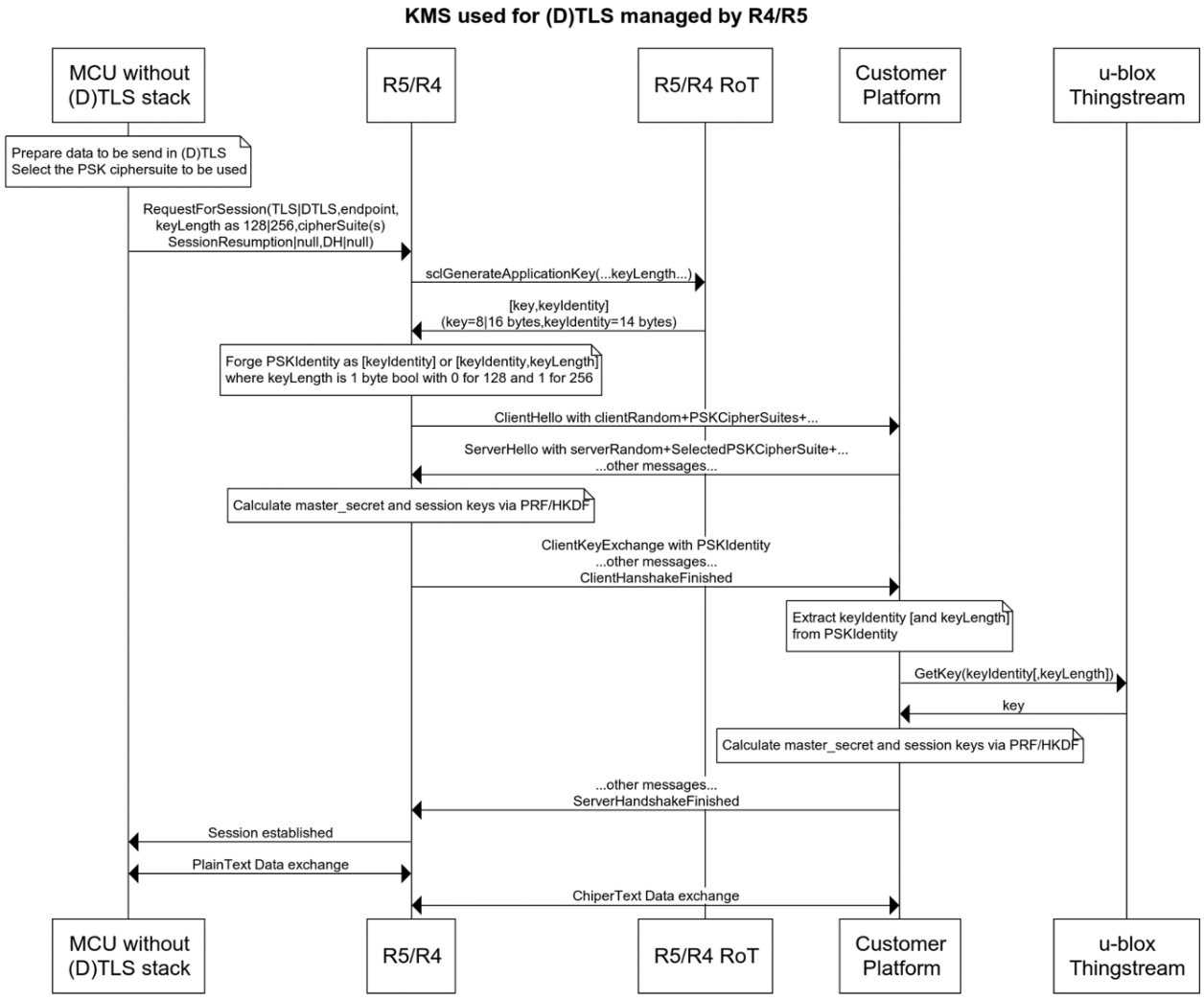


Figure 15: Key management service process managed by SARA-R4/R5 module

6.1.1 Use case

6.1.1.1 Option 1

Once the device has been bootstrapped and the pre-shared keys (PSK) provisioning functionality has been enabled, this functionality can be called to access the required keys, as described below:

1. The customer's application running on the device makes a request to the u-blox module and retrieves a PSK and PSKIdentity pair from the RoT by using the AT+USECPSK command.
2. The customer configures their own (D)TLS stack to use the PSK and PSKIdentity that are retrieved to secure the communication with its endpoint.
3. The PSKIdentity is sent during the (D)TLS handshake as the "Identity" element of the ClientKeyExchange message, and the PSK is used to encrypt/decrypt the (D)TLS session data.
4. The customer's remote service extracts the PSKIdentity from the ClientKeyExchange message and forwards it to the u-blox security service via the GetPSK API.
5. The information received by the u-blox security service is used to:
   5.1. Validate the customer
   5.2. Validate the device making the request is assigned to this customer account
   5.3. Confirm that PSK provisioning is enabled on this device
6. If all the actions in item 5 are true, i.e. the request is valid, then the u-blox security service passes the PSK back to the customer's remote service in the GetPSK API response.
7. The customer's remote service can now use the received PSK to establish the (D)TLS session.

The following AT command can be used to retrieve an identity and PSK value pair for encrypting point-to-point communication:

Command	Response	Description
AT+USECPSK=16	+USECPSK: "110100000011223344556677889 9","DEDD8D0A62D9D24059F392688D738236" OK	It retrieves the PSK key identity and the PSK key in hex format.

The module includes a (D)TLS security layer profile manager, which handles security profiles containing (D)TLS connection properties. Each security profile can be associated to sockets or higher level applications (e.g., HTTP, MQTT) using the module internal (D)TLS stack. In general, the AT+USECPRF command is used to configure a security profile.

The following AT commands can be used to configure a security profile on the module with certain PSKIdentity and PSK:

Command	Response	Description
AT+USECPRF=0,8,"DEDD8D0A62D9D24059F392688D738236",1	OK	Set PSK for security profile 0, in hex string format. This PSK will be used to encrypt communication on secure sockets/applications associated to USECMNG profile 0.
AT+USECPRF=0,9,"110100000011223344556677889 9"	OK	Set PSKIdentity for security profile 0, as an ASCII string. This PSKIdentity will be used to initiate connection of secure sockets/applications associated to USECMNG profile 0.

This way, associating a TCP socket to security profile 0, PSKIdentity and PSK will be used to handle the TLS communication through that TCP socket.

Examples

Following are some examples of the procedure described above.

☞ These are example commands and do not use real world API keys or authorization headers. Actual API secret key and authorization headers must first be created before running these commands.

1. Get PSK and PSKIdentity from RoT. For example, get a 16 bytes long PSK:

```
AT+USECPSK=16
+USECPSK: "11010008002F33244B115B0AEEB9","E5DE45B367DB690F2E17CF9D80A18E87"
OK
```

   - 11010008002F33244B115B0AEEB9 is the PSKIdentity in hex format: this has to be sent to the remote service during the (D)TLS handshake.
   - E5DE45B367DB690F2E17CF9D80A18E87 is the actual PSK in hex format: this can be used to encrypt the communication to the remote service.

2. Configure the (D)TLS stack to use the PSKIdentity and PSK generated by RoT.

   This step depends on the (D)TLS stack used. We provide 2 examples:

   a) Use OpenSSL command to test the connection to the remote service. Call OpenSSL this way:

```
openssl s_client -psk_identity "11010008002F33244B115B0AEEB9" -psk
"E5DE45B367DB690F2E17CF9D80A18E87" -connect <server_IP:server_port>
```

   b) Use a modem internal socket to communicate to the remote service.

      Configure a security profile (profile 0 in this example):

```
AT+USECPRF=0,8,"E5DE45B367DB690F2E17CF9D80A18E87",1
OK
```

```
AT+USECPRF=0,9,"11010008002F33244B115B0AEEB9"
OK
```

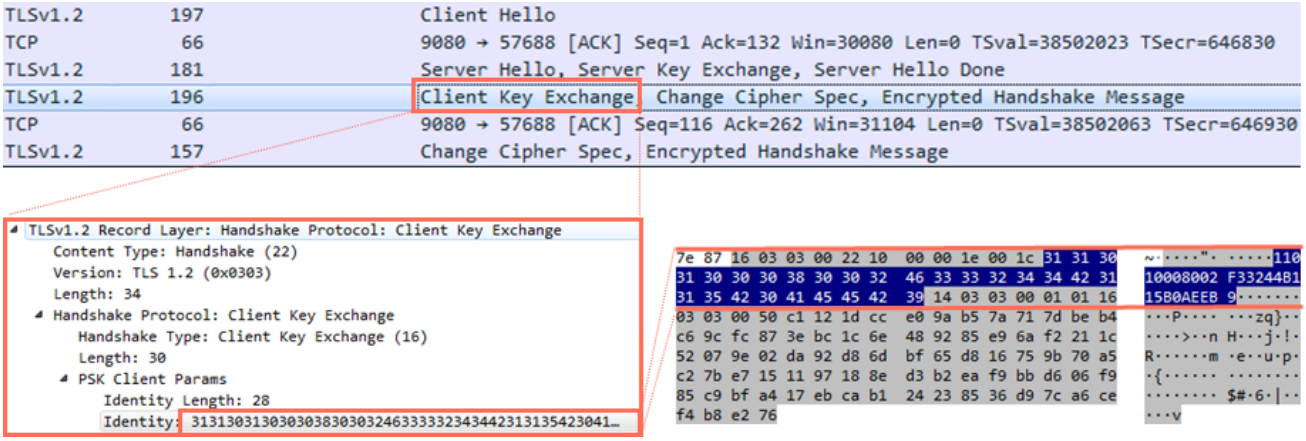
Then, create a socket and enable the secure option on the socket, associating the security profile 0 to it:

```
AT+USOCR=6
+USOCR: 0                    ← created socket with id 0
OK
AT+USOSEC=0,1,0              ← associate socket 0 to security profile 0
OK
```

Connect the socket to the remote service:

```
AT+USOCO=0,"<server_IP>",<server_port>
```

3. Analyzing the communication between client and remote service, we can see the PSKIdentity being sent by the client in the ClientKeyExchange message during (D)TLS handshake:



4. Now we're on the remote service side.

   The actual way to extract the PSKIdentity from the ClientKeyExchange message can vary and depends on the (D)TLS stack used.

   For example, a server application using OpenSSL libraries and wishing to use PSKs for TLSv1.2 and below must provide a callback function called when the server receives the ClientKeyExchange message. This function has the purpose of fetching the correct PSK starting from the PSKIdentity retrieved from the client. The callback function is set by calling SSL_CTX_set_psk_server_callback(SSL_CTX *ctx, SSL_psk_server_cb_func cb):

```
#include <openssl/ssl.h>
#include <openssl/err.h>
…
SSL_CTX *ctx;
const SSL_METHOD *method;

method = SSLv23_server_method();
ctx = SSL_CTX_new(method);
if (!ctx) {
    ERR_print_errors_fp(stderr);
    return -1;
}
SSL_CTX_set_ecdh_auto(ctx, 1);
SSL_CTX_use_psk_identity_hint(ctx, "hint hint");
SSL_CTX_set_psk_server_callback(ctx, psk_server_cb);
```

During (D)TLS handshake, when the server receives the ClientKeyExchange message, the psk_server_cb function is called.

```
static unsigned int psk_server_cb(SSL *ssl,
                                  const char *identity,
                                  unsigned char *psk,
                                  unsigned int max_psk_len) {
    char* py_psk;

    if (identity == NULL) {
        return 0;
    }

    /* Retrieve the PSK for the given identity */
    /* … */
```

See OpenSSL documentation for more details (https://www.openssl.org/docs/).

Once the PSKIdentity is retrieved, the customer can obtain the PSK via the GetPSK REST API call (https://ssapi.services.u-blox.com/v1/GetPSK). Make sure to have an AuthToken to use for the Authorization header – if not, call the Authorize API to get one.

We show the API call using cURL: we have to specify the PSKIdentity in the KeyID parameter and, optionally, the PSK length (in bits) in the KeyLength parameter:

```
curl -X POST "https://ssapi.services.u-blox.com/v1/GetPSK" -H "accept: application/json" -H "Authorization: [AuthToken]" -H "Content-Type: application/json" -d "{ \"KeyID\": \"11010008002F33244B115B0AEEB9\", \"KeyLength\": \"128\"}"
```

In the previous C server application, it's possible for example to use the libcurl library to perform the API request. See libcurl documentation for more details (https://curl.haxx.se/libcurl/c/).

5. (Steps 5-6) The API returns a JSON containing the PSK encoded using base64:

```
{
    "Key": "5d5Fs2fbaQ8uF8+dgKGOhw==",
    "ROTPublicUID": "0002000089282245"
}
```

7. Considering the C server application from above, at this point the server can create a server socket (sock_fd) and wrap it with the OpenSSL context from before (ctx):

```
SSL *ssl;

const SSL_METHOD *method;
method = SSLv23_server_method();

SSL_CTX_set_ecdh_auto(ctx, 1);
SSL_CTX_use_psk_identity_hint(ctx, "hint hint");
SSL_CTX_set_psk_server_callback(ctx, psk_server_cb);

ssl = SSL_new(ctx);
if (ssl == NULL) {
```

```
        // Failed to initialise SSL buffer
        return NULL;
    }
    if (0 == SSL_set_fd(ssl, sock_fd)) {
        // Failed to configure IO for the SSL socket
        ERR_print_errors_fp(stderr);
        return NULL;
    };

    if (SSL_accept(ssl) <= 0) {
        // Failed to setup SSL socket as server
        ERR_print_errors_fp(stderr);
        SSL_free(ssl);
        return NULL;
    }
```

At this point, the server application can exchange data through the secure socket by using SSL_read() and SSL_write. See OpenSSL documentation for more details (https://www.openssl.org/docs/).

6.1.1.2 Option 2

⚠ This scenario will be supported in the next FW release of SARA-R5 (not in SARA-R4-x3B product family)

A security manager profile can also be configured to generate a PSK and PSKIdentity pair automatically when a socket negotiates a (D)TLS connection. In this case there is no need for further configuration of the security profile (PSK and PSKIdentity) or configuration of external (D)TLS stack.

Once the device has been bootstrapped and the E2E Symmetric KMS functionality has been enabled, use the following +USECPRF AT command for enabling automatic PSK and PSKIdentity generation for the security profile number 0:

Command	Response	Description
`AT+USECPRF=0,11,1`	`OK`	Enable for the security profile id 0 the use of PSK and PSK identity during TLS connection negotiations.

All applications that rely on the security profile number 0 will now transmit the generated identity value in the “Identity” field of the ClientKeyExchange message during (D)TLS handshake procedure in order to negotiate the session keys.

☞ An external connection must be available, via a suitable SIM card, to run the following command otherwise the following error result code will be displayed: `+CME ERROR: No connection to phone`

Command	Response	Description
`AT+USOCR=17`	`+USOCR: 0` `OK`	Create a UDP socket.
`AT+USOSEC=0,1,0`	`OK`	Enable SSL/TLS/DTLS on the socket #0 and specify to use the profile id 0.
`AT+USOCO=0,"myservice.com",443`	`OK`	Connect the socket 0 to the server ‘myservice.com’ on port 443.

In a similar way the PSK can be used to secure an HTTP connection (in the following example the profile id 0 configured previously is re-used):

Command	Response	Description
AT+UHTTP=0,1,"myservice.com"	OK	Set the HTTP server name for profile id 0.
AT+UHTTP=0,6,1,0	OK	Enable SSL and use the security profile id 0 for the HTTP profile #0.
AT+UHTTPC=0,1,"/"	OK	Send the GET command.

6.2 End-to-end data protection

End-to-end data protection provides application layer encryption to device and module applications. The application data is encrypted in the module and the corresponding decryption key and parameters are made available via the REST API in the cloud for decryption.

The data can be:

- Encrypted on the device.
- Transferred over the internet independent of the protocols, servers or platforms used to achieve this.
- Decrypted at a time of own choosing in the future.

The process does not depend on the security of the transport layers or storage mechanisms used between the device and the end service.

☞ Note that on step (4) key identity will the first 11 or 16 bytes of the payload.

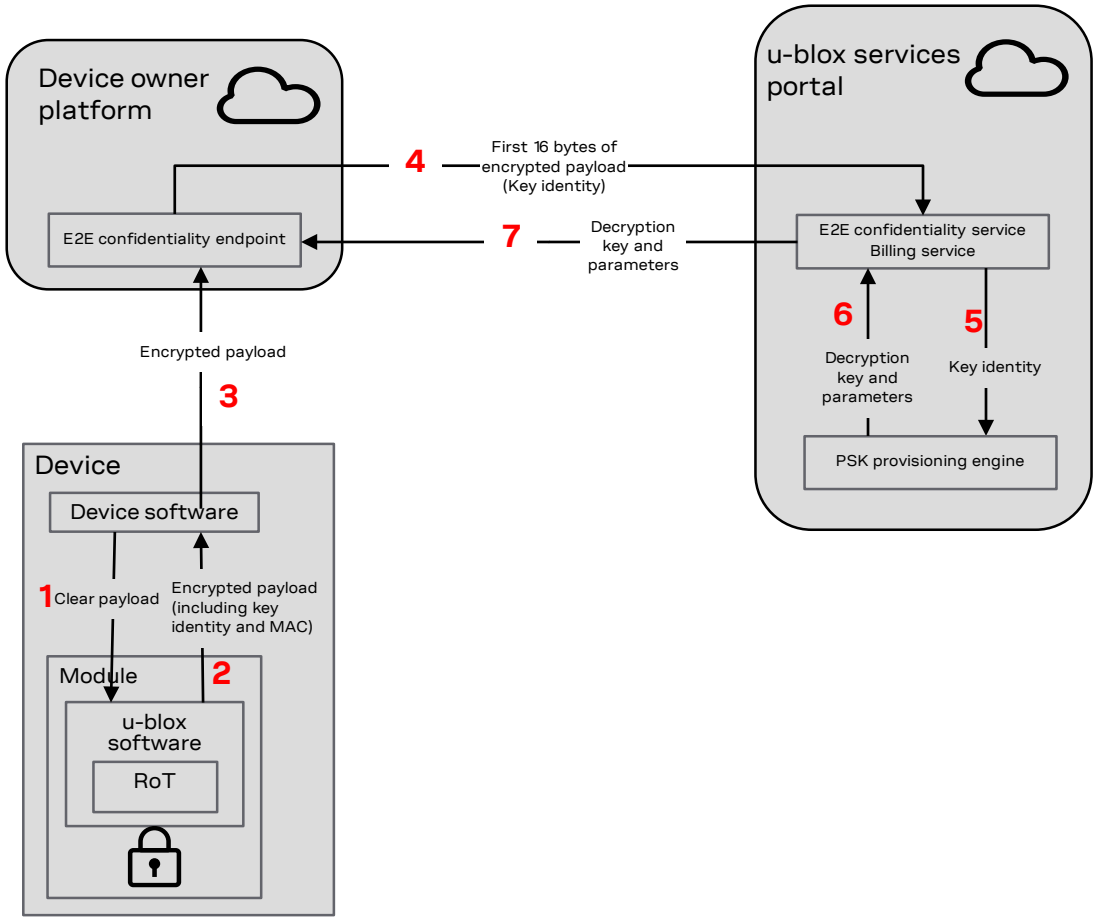
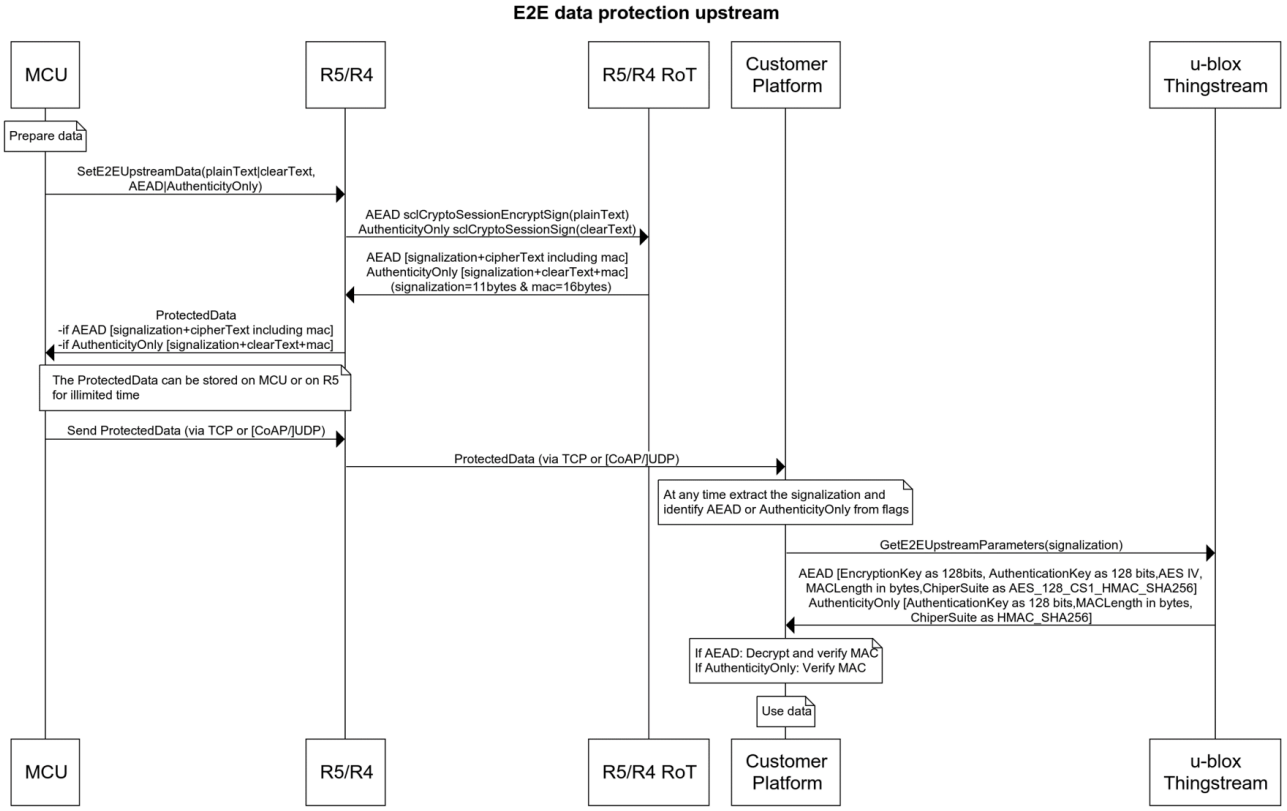


Figure 16: End-to-end data protection

6.2.1 Upstream (device to cloud)

The application layer (device) wants to send a message to cloud securely without being involved in the security stack. The sequence diagram below demonstrate the main players and the interactions between them.



The diagram below demonstrates the steps from device to cloud.

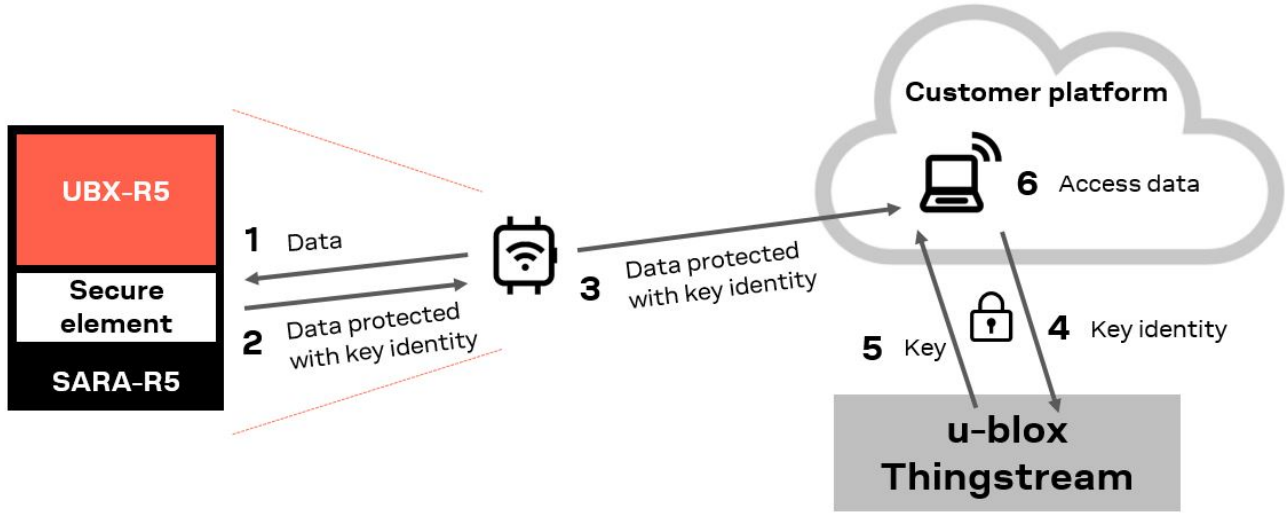
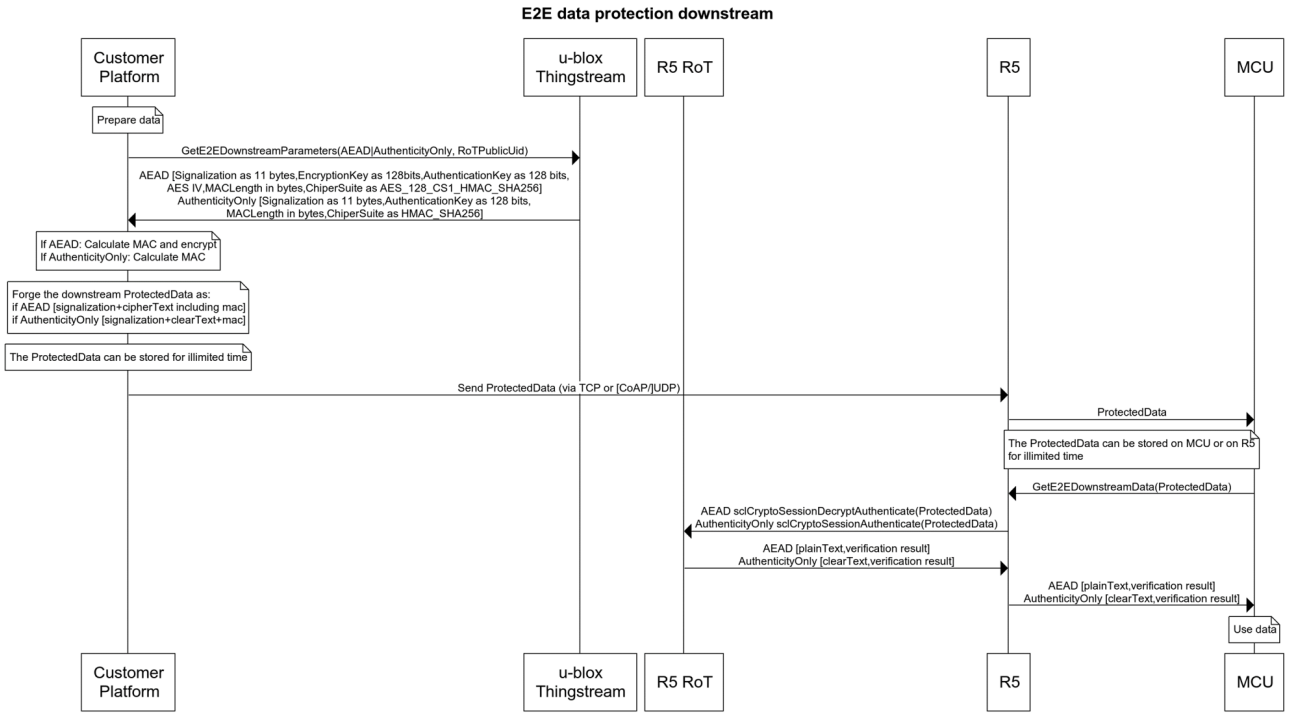


Figure 17: Security steps from device to cloud

6.2.2 Downstream (cloud to device)

This service will be available in near future. In this scenario cloud would like to send a message to a particular device securely. The sequence diagram demonstrates the players that the interactions between them.



The diagram below demonstrates the steps from cloud to device.

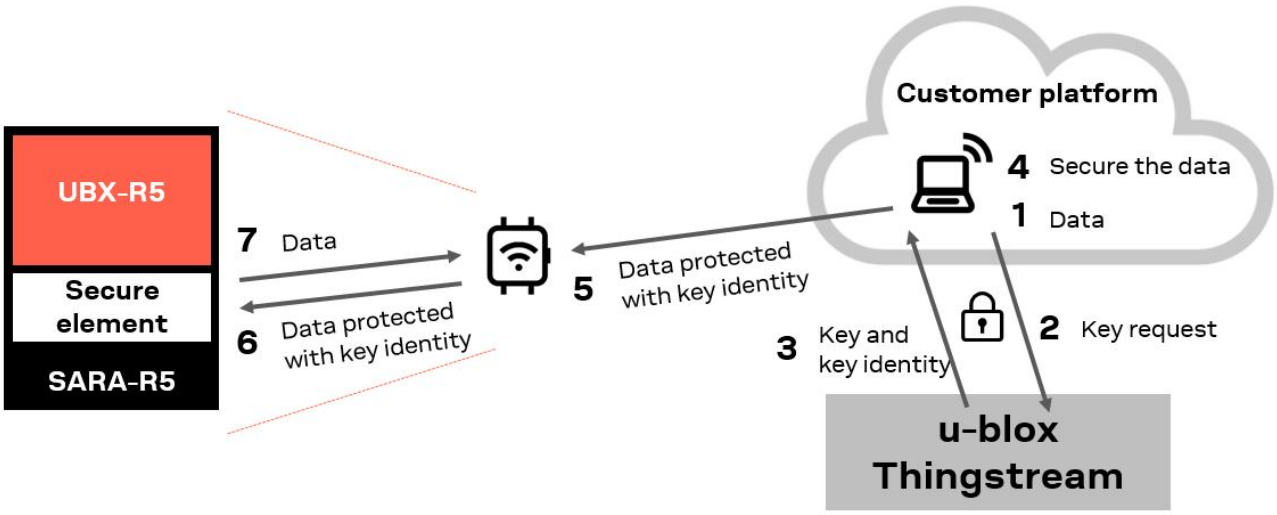


Figure 18: Security steps from cloud to device

6.2.3 Use case

Once the device has been bootstrapped and the end-to-end data protection functionality has been enabled, the end-to-end encryption functionality can be called, as described below:

1. The customer's application running on the device makes an end-to-end encryption request to the u-blox module on the same device passing the data to be encrypted by using the AT+USECE2EDATAENC or the AT+USECE2EFILEENC command.
2. The u-blox module on the device encrypts the data and passes the authenticated and encrypted data back to the customer's application.
3. The customer's application can then forward the authenticated and encrypted data to the customer's remote service using whatever means they choose. This may not be a direct call to the customer's remote service but may involve the transporting of the data via 1 to [N] insecure internet servers (corresponding to step 3 in Figure 16).

   During this transport phase the security and integrity of the data is still maintained as the data is encrypted and authenticated.

   The data can be retained by the customer's remote service for decryption at a later date.
4. The key identity is extracted from the authenticated and encrypted data by reading the first KI_LENGTH bytes, where KI_LENGTH is defined by the 4 most significant bits (nibble) in the encrypted data:
5. If the nibble is set to 0x1, then KI_LENGHT is 16 bytes.
6. If the nibble is set to 0x2, then KI_LENGTH is 11 bytes.
   The key identity is forwarded to the u-blox security service via GetE2EDecryptionParameters API call, so that the matching decryption key and decryption parameters can be retrieved.
7. The information received by the u-blox security service is used to:
8. Validate the customer.
9. Validate the device making the request – Verify if this device is assigned to this customer account
10. Confirm that end-to-end data protection is enabled on this device
11. If all the actions in item 5 are true, i.e. the request is valid then the u-blox security service passes the decryption key and decryption parameters back to the customers' remote service.
12. The customers remote service can now decrypt and verify the authenticity of the data previously passed to it (see item 3).
13. The decrypted data can now be used as required by the customer's remote service.

The AT command +USECE2EDATAENC can be called to encrypt data:

Command	Response	Description
AT+USECE2EDATAENC=13 > datatoencrypt	45,"••••‰("Mv3ðX~y•••,••• ïÚ«S&p•"}•7D'?T¼}sÞ‰^÷WÙ" OK	The command encrypts the secret string 'datatoencrypt', reading it from the AT interface, and writes to AT interface the encrypted data, in binary form, that can be decrypted at a later date at a different location.

This operation corresponds to step 2 in Figure 16.

Examples

Following are some examples of the procedure described above.

☞ These are example commands and do not use real world API keys or authorization headers. Actual API secret key and authorization headers must first be created before running these commands.

1. (Steps 1-2-3) Let's encrypt a simple «HELLO» message using AT+USECE2EDATAENC.

Use m-center in HEX mode (enable the checkbox on the top in the AT terminal). This way it's easier to parse the encrypted data returned by the AT command.

The AT command to send is:

```
AT+USECE2EDATAENC=5
> HELLO
```

The command returns the length of the encrypted data and the encrypted data itself:

```
+USECE2EDATAENC: 37, "<encrypted_data>"
```

```
41 54 2b 55 53 45 43 45 32 45 44 41 54 41 45 4e | AT+USECE2EDATAEN
43 3d 35 0d                                     | C=5•
3e                                              | >
48 45 4c 4c 4f 0d                               | HELLO•
3c                                              | <
0d 0a 2b 55 53 45 43 45 32 45 44 41 54 41 45 4e | ••+USECE2EDATAEN
43 3a 20 33 37 2c 22 11 01 00 00 89 29 1e 26 ec | C: 37,"••••%)•&ì
1a eb 00 74 45 00 00 0b 87 4c 81 e9 1d 62 3a dd | •ë•tE•••‡L é•b:Ý
f6 3b ce be 64 fe 8b 29 0e fb 4c d7 22 0d 0a    | ö;Î¾dþ‹)•ûL×"••
0d 0a 4f 4b 0d 0a                               | ••OK••
```

In this case we get 37 bytes of encrypted data, which in hex format is:

```
1101000089291e26ec1aeb00744500000b874c81e91d623addf63bcebe64fe8b290efb4cd7
```

This is the encryption part of the process. At this point the encrypted data can be transferred to the recipient by secure or insecure means.

The encrypted and authenticated data returned by the AT+USECE2EDATAENC command is composed, in order, by:

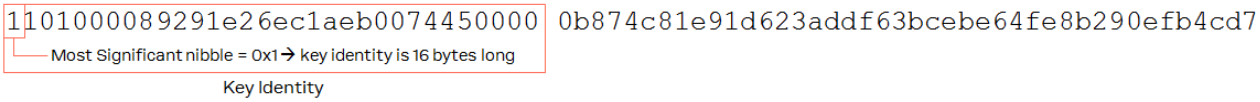
- The key identity to be used in order to request decryption parameters.
- The cipher text.
- The MAC tag used to authenticate the data.

2. (Step 4) Suppose we are ready to decrypt the message – this could happen on any host that has received the encrypted data at any time.

   First thing to do is to extract the key identity from the encrypted data. The most significant nibble (4 bits) of the encrypted data define the key identity length:

   - If the nibble is set to 0x1, then the key identity is 16 bytes long.
   - If the nibble is set to 0x2, then the key identity is 11 bytes long.

   In our example we have:



   Since the most significant nibble is 0x1, we extract the first 16 bytes:

   Key identity: `1101000089291e26ec1aeb0074450000`

   The data encrypted using the +USECE2EDATAENC and +USECE2EFILEENC AT commands can only be decrypted using a key obtained using the GetE2EDecryptionParameters REST API (https://ssapi.services.u-blox.com/v1/GetE2EDecryptionParameters). Make sure to have an AuthToken to use for the Authorization header – if not, call the Authorize API to get one.

   Specifically, the REST API will provide the key and algorithm details needed to decrypt and verify the authenticity of the cipher text generated by +USECE2EDATAENC and +USECE2EFILEENC.

   The following command line examples use cURL to retrieve the PSK and decryption details, by sending the key identity previously extracted in the "EncryptedHeader" parameter.

Request to be run on Linux and macOS:

```
curl -X POST "https://ssapi.services.u-blox.com/v1/GetE2EDecryptionParameters" -H
"accept: application/json" -H "Content-Type: application/json" -H Authorization:
[AuthToken] -d '{"EncryptedHeader":"1101000089291e26ec1aeb0074450000"}'
```

Request to be run on Windows:

```
curl -X POST "https://ssapi.services.u-blox.com/v1/GetE2EDecryptionParameters" -H
"accept: application/json" -H "Content-Type: application/json" -H Authorization:
[AuthToken] -d "{\"EncryptedHeader\":\"1101000089291e26ec1aeb0074450000\"}"
```

3. (Steps 5-6) If the request succeeds, the API response contains a JSON with this information:

```
{
    "CipherSuite": "AES_128_CCM",
    "Key": "ds/zy+Co/XYVMa14bqFh3w==",
    "MACLength": 128,
    "Nonce": "iSkeJuwa6wB0RQAA"
}
```

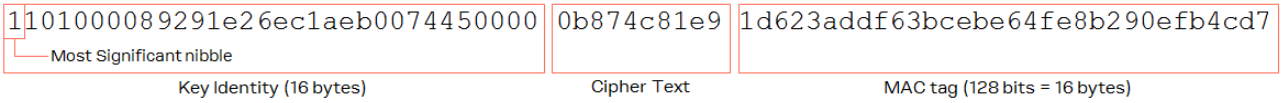
☞ The KI_LENGTH bytes long header returned by +USECE2EDATAENC and +USECE2EFILEENC, when converted to an HEX string, is used in the curl request as the value of the EncryptedHeader parameter.

The key and nonce values returned are base-64 encoded, and can be used to decode the ciphertext, i.e. the data returned by +USECE2EDATAENC and +USECE2EFILEENC after having removed the KI_LENGTH bytes header, using the algorithm specified, in this case AES with the CCM mode. The MAC (16 for CCM mode or 8 bytes for CCM_8 mode) is appended at the end of the encrypted payload and it must be verified by the customer.

4. (Step 7) From the API response we know:

- That we need to use the AES_128_CCM algorithm to decrypt the message
- The key and the nonce parameter to use as inputs for the algorithm
- That the MAC tag is 128 bits long (16 bytes)

Since the MAC tag is appended to the cipher text in the encoded data, we can now split the response of AT+USECE2EDATAENC this way:



At this point we have all the inputs to decrypt and authenticate the encrypted data.

From the API response:

- Algorithm to use.
- Key and nonce.

From the encrypted AT+USECE2EDATAENC response:

- Cipher text.
- MAC tag.

We provide, as an example, a Python snippet which decrypts the cipher text by using the PyCryptodome package (https://pycryptodome.readthedocs.io/en/latest/):

```
from base64 import b64decode
from Cryptodome.Cipher import AES
import binascii
```

```
def aesccm_dec(enc_data, keyb64, nonceb64, mac_len):
    '''
    Decrypt a cipher text using AES-CCM algorithm.
    :param enc_data: the encrypted data string returned by AT+USECE2EDATAENC
    :param keyb64: the decryption key returned by GetE2EDecryptionParameters
    :param nonceb64: the nonce returned by GetE2EDecryptionParameters
    :mac_len: the MAC tag length returned by GetE2EDecryptionParameters
    '''
    # decryption key and nonce are given by the API response as base64 strings
    # they need to be converted to bytes (binary data)
    key = b64decode(keyb64)
    nonce = b64decode(nonceb64)
    # ciphertext and MAC tag are extracted from the encrypted data as hex strings
    # get key identity and MAC tag lengths
    mac_len = mac_len // 8      # convert to bytes
    key_id_len = 16 if enc_data[0] == '1' else 11     # in bytes
    # get ciphertext and MAC tag and convert them to bytes (binary data)
    ciphertext = binascii.unhexlify(enc_data[key_id_len*2:-mac_len*2])
    tag = binascii.unhexlify(enc_data[-mac_len*2:])
    try:
        cipher = AES.new(key, AES.MODE_CCM, nonce=nonce)
        plaintext = cipher.decrypt_and_verify(ciphertext, tag)
        print("The message is: " + plaintext.decode('utf-8'))
    except (ValueError, KeyError) as ex:
        print("Incorrect decryption")
        print(ex)
```

Running this function with the data from the example we get back our original “HELLO” message.

6.3 TLS version

TLS is a cryptographic protocol used to increase security over computer networks. TLS is the successor of SSL although it is sometimes still referred to as SSL. It provides privacy and data integrity between a TCP client (e.g., device) and a server. It ensures that data is reliable, comes from an authenticated party, and is protected against ‘man-in-the-middle’ attacks.

☞ SARA-R4 "63B", "73B", “83B” product versions implement TLS v.1.2.

6.4 DTLS version

DTLS is a communications protocol designed to protect data privacy and prevent eavesdropping and tampering. It is based on TLS and the main difference between DTLS and TLS is that DTLS uses UDP and TLS uses TCP. It provides privacy and data integrity between a UDP client (e.g., device) and a server. It ensures that data is reliable, comes from an authenticated party, and is protected against ‘man-in-the-middle’ attacks.

☞ SARA-R4 "63B", "73B", “83B” product versions implement DTLS v.1.2.

7 Access control

7.1 Zero Touch Provisioning

Zero touch provisioning is an automatic and secure way to enable and properly configure devices' access to cloud services during deployment. It is an affordable (automatic) and secure way to enable and properly configure our devices during deployment to connect to Core Cloud Services.

In order to access such services, the device must be identified and authorized. This is done by generating and sending appropriate information (provisioned TLS certificates and keys) to the service provider.

u-blox Security Service provides suitable certificates/keys to the module, and AT commands can be used by the device connected to the module to retrieve this information.

Zero Touch Provisioning (ZTP) supports X. 509 standard as the format of public-key certificates so any platform supporting this standard will be compatible with this service. Amazon Web Services (AWS), Microsoft Azure and Alibaba cloud are some example platforms fully supported by ZTP.

Following are the steps in ZTP cloud onboarding procedure:

- Service (ZTP) registration
- Certificate provisioning
- Device registration

In this section we will go to details and explain these steps with more details.

7.1.1 Service registration

The operation can take place only once for the entire set of devices. The client is provided with a registration code and a CA is generated if needed. In the diagrams bellow AWS is mentioned as the example of a platform supporting X.509 standard.

☞ Please note that ISEP and CSP are two components of u-blox Thingstream platforms.

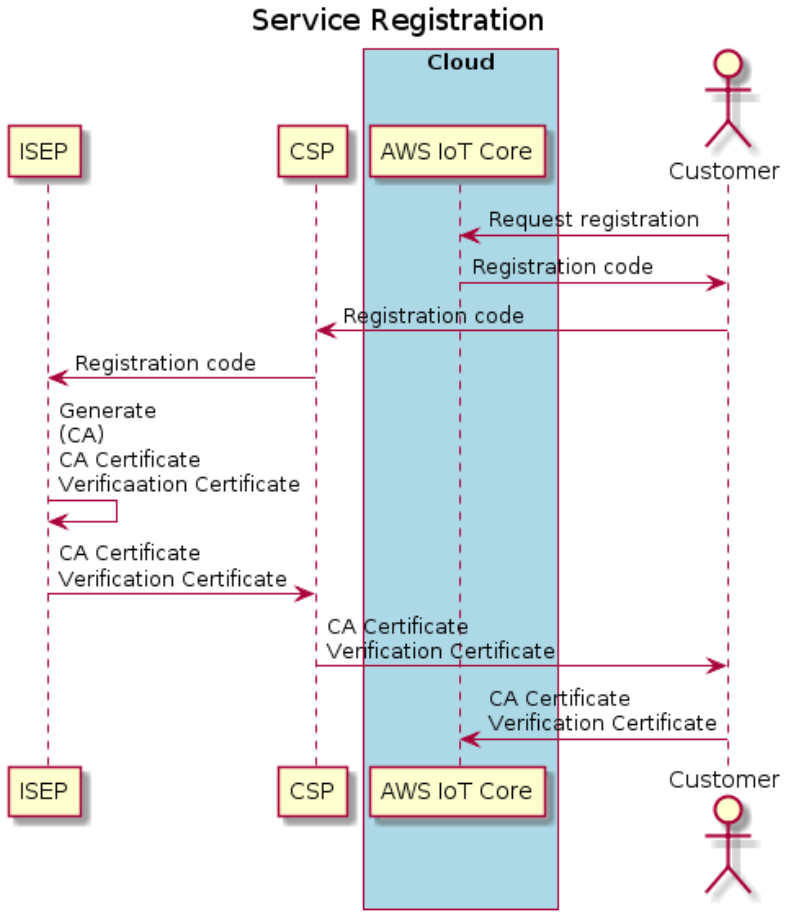


Figure 19: Service registration

7.1.2 Certificate provisioning

Operation triggered by the module when it connects to ISEP for the first time in its life cycle.

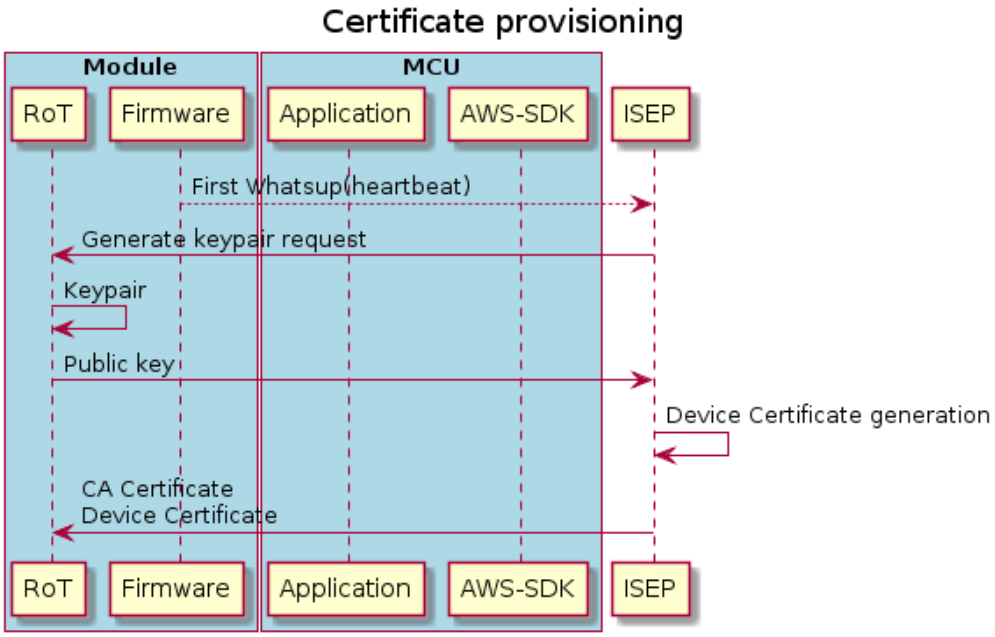


Figure 20: Certificate provisioning

7.1.3 Just in time provisioning

Operation made when the device connects to the Cloud for first time in its life cycle. The IoT Core is provided with a Device certificate together with a PoP.

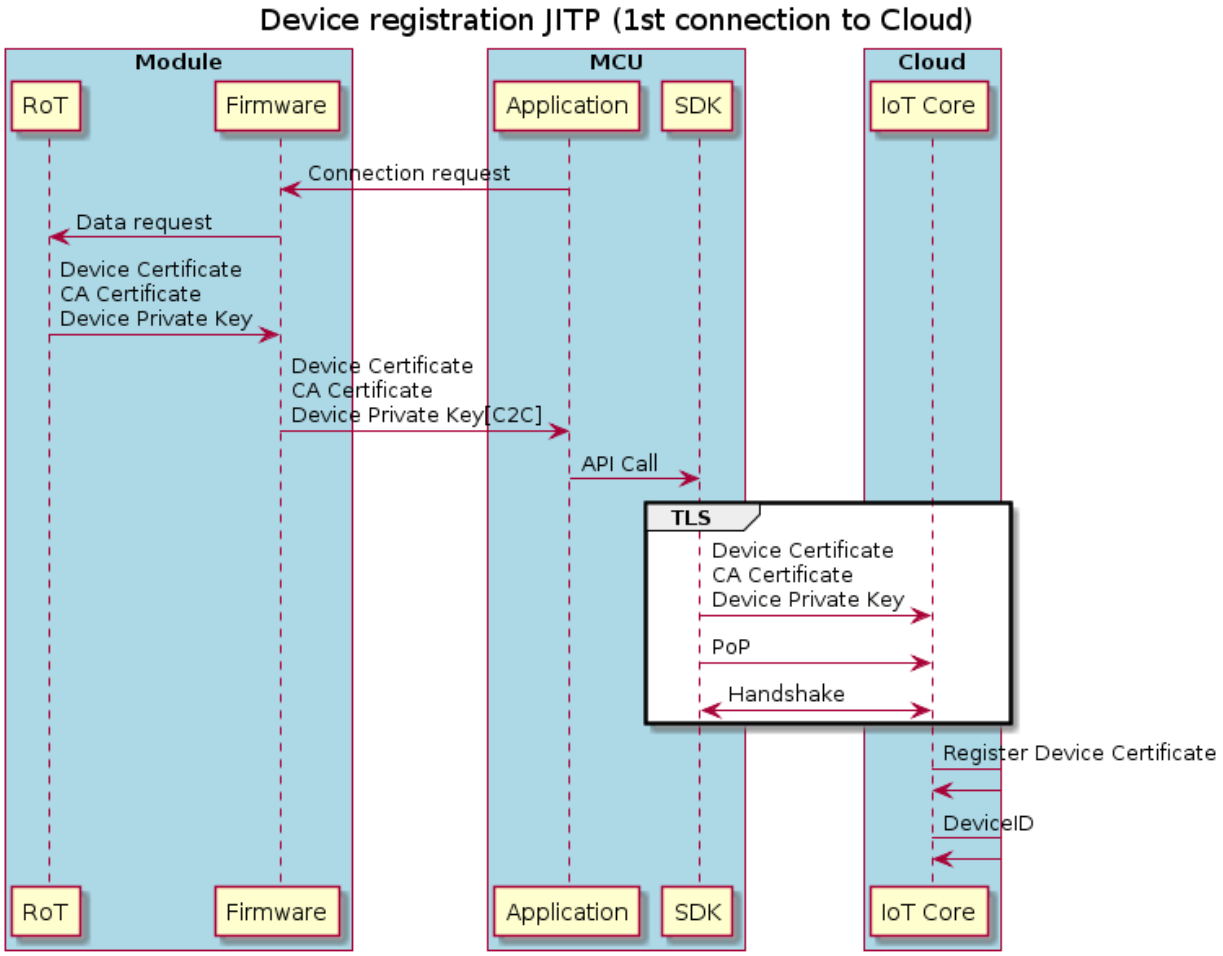


Figure 21: First time device connects to the cloud

7.1.4 Device registration

Operation triggered every time the module requests an IoT Service.

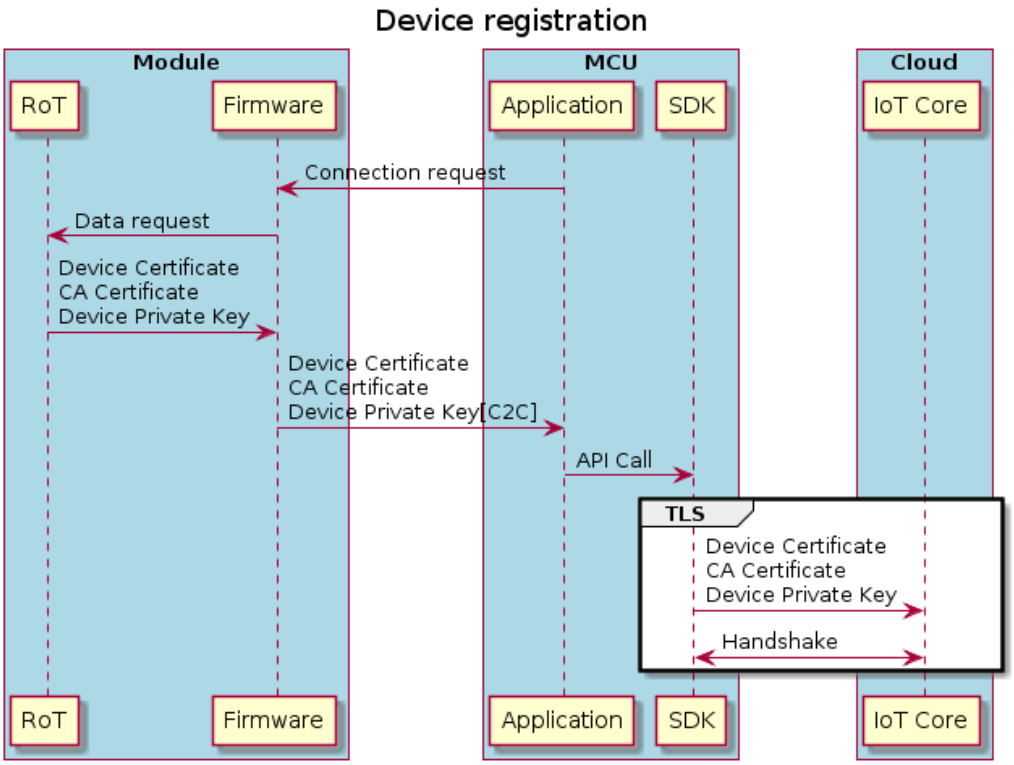


Figure 22: Device registration for each service request

Ztp feature involves 4 different parameters to be used in AT command +USECDEVCERT Command:

0: Check provisioning: +USECDEVCERT=0

returns 0 if CaCertificate, DeviceCertificate and PrivateKey are present in RoT

1: Get CA Certificate: +USECDEVCERT=1

Returns the CACertificate

2: Get Device Certificate: +USECDEVCERT=2

Returns the DeviceCertificate

3: Get Private Key: +USECDEVCERT=3

Returns the PrivateKey

☞ For more information on the response time is provided in AT command manual. (You can search the “AT command manual” for +USECCONN)

7.1.5 Use case (ZTP for Amazon Web Services)

Once the customer has an account on the AWS cloud platform, the below procedure can be followed in order to provision a device with necessary certificates/keys to connect to the AWS IoT Core service by using ZTP.

Needed tools: access to u-blox Security Service API, access to AWS IoT Core CLI, access to AT interface.

The procedure is slightly different depending if the device(s) have already bootstrapped or not.

Here is the procedure:

1. Customer creates a CA certificate on the u-blox Security Service by calling the suitable API: /ztp/rootca/create. The API returns the CA certificate, which can be locally stored in a file.
2. Customer gets its AWS IoT registration code (or Proof of Possession verification code) by using the AWS CLI.
3. Customer generates a Proof-of-Possession certificate on u-blox Security Service, by calling the suitable API: /ztp/rootca/popcertificate/generate. The API returns the PoP certificate, which can be locally stored in a file.
4. Customer registers and activates the CA certificate got from u-blox Security Service on AWS IoT, by using the AWS CLI or the AWS web console.
5. Customer enables the ZTPV1 feature on device:
   5.1. If the module is already bootstrapped, call the API /device/provisioning/set.
   5.2. If the module is not bootstrapped yet, call the API /deviceprofile/bootstrapprovisioning/set.
   5.3. You can always check the feature authorization status by using the API /device/provisioning/get.
6. At next synchronization of the module with the u-blox Security Service (bootstrap completion or next security heartbeat message), the certificates and keys for AWS connection will be provisioned to the device automatically. In order to get CA certificate, device certificate and device private key, the customer's application running on the device can use thte AT+USECDEVCERT command on the module.
7. Customer registers the device certificate on AWS IoT by using the AWS CLI.
8. Customer creates and configures a Thing on AWS IoT by using the AWS CLI.
9. Customer can now connect the provisioned device to AWS and perform traffic by using any external client of choice, e.g., AWS SDK.

Example

(Step1-4) First of all, we need to get a CA certificate from the u-blox Security Service to use for ZTP and register it into the AWS cloud platform. These operations are a prerequisite to the ZTP feature activation on the module, so they must be performed prior to it.

We call the API at https://ssapi.services.u-blox.com/v1/ztp/rootca/create to ask for a CA certificate and pass a name for the CA certificate (used to identify it in later actions), and the validity time both for the CA certificate and the device (or client).

Let's for example create a "test-ca" CA certificate. We'll send to the above API this content:

```
{
    "CAName": "ubxaecel-ztp-aws-ca",
    "CACertificateValidity": 1825,
    "DeviceCertificateValidity": 1825
}
```

And we'll receive a response like the following:

```
{
    "CAName": "test-ca",
    "CACertificateValidity": 1825,
    "DeviceCertificateValidity": 1825,
    "Certificate": "-----BEGIN CERTIFICATE<...>-----END CERTIFICATE-----",
    "CreatedDate": "2020-07-03T09:07:44Z"
}
```

Save the CA certificate's contents (here truncated) into a file.

Next, we need to create a Proof-of-Possession verification certificate from the u-blox Security Service, and to do this we need the AWS IoT registration code associated to our AWS account. If you don't already have this information, you can get it by using the AWS CLI:

```
C:> aws iot get-registration-code
{
    "registrationCode": "11fe30cf95<...>838a01be8313c"
}
```

Now we can call the https://ssapi.services.u-blox.com/v1/ztp/rootca/popcertificate/generate API passing to it the CA certificate name used before and the AWS registration code:

```
{
    "CAName": "test-ca",
    "RegistrationCode": "11fe30cf95<...>838a01be8313c"
}
```

And we'll get a response like the following:

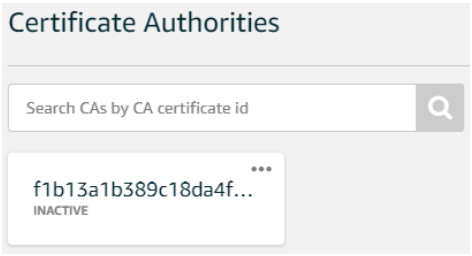
```
{
    "CAName": "test-ca",
    "PoPCertificate": "-----BEGIN CERTIFICATE-----<...>-----END CERTIFICATE-----"
}
```

Save the PoP verification certificate contents (here truncated) into a file.

Now we have all the data to register the CA certificate into AWS IoT, and we do this by using the AWS CLI:

```
C:> aws iot register-ca-certificate --ca-certificate file://test-ca.pem --
verification-cert file://test-pop.pem
{
    "certificateArn": "arn:aws:iot:eu-central-
1:27<...>24:cacert/f1b13a1b389c18d<...>0365ebba1",
    "certificateId": "f1b13a1b389c18d<...>0365ebba1"
}
```

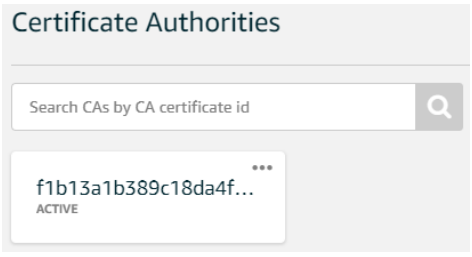
By visiting the AWS IoT web console, we can now see that an entry appeared in the Certificate Authorities section:



As you can see, the CA certificate is currently inactive, so we need to activate it, and we can do this by using the AWS CLI – reference the certificate id returned by the previous command:

```
C:> aws iot update-ca-certificate --certificate-id " f1b13a1b389c18d<...>0365ebba1" --new-
status ACTIVE
```

Now we can see on the AWS IoT web console that the status of the CA certificate is active:



(Step 5) Enable the ZTP feature on the device.

This can be done before the module bootstrapped or after the module bootstrapped: different APIs have to be used depending on the case.

If the module is not bootstrapped, you need to provide the DeviceProfileUID sealed in the module and the CA certificate name created before.

If the module is already bootstrapped, you need to provide the ROTPublicUID of the module and the CA certificate name created before.

(Step 6-7) Once the ZTP feature is enabled on the module, the needed certificates/keys will be provided by the u-blox Security Service to the module at bootstrap completion or at next security heartbeat. You can get the provisioned data from the module by using the AT+USECDEVCERT command.

The read command provides a status of the provisioning: if all the numbers returned by the command are 0, it means that all the needed data have been provisioned:

```
AT+USECDEVCERT?
+USECDEVCERT: 0,0,0
OK
```

At this point, you can get the device (or client) certificate and key by using:

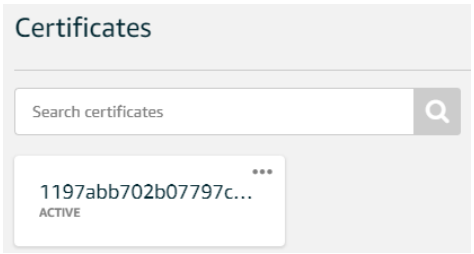
```
AT+USECDEVCERT=1
+USECDEVCERT: 1,"-----BEGIN CERTIFICATE-----
<...>
-----END CERTIFICATE-----
"
OK
AT+USECDEVCERT=0
+USECDEVCERT: 0,"-----BEGIN EC PRIVATE KEY-----
<...>
-----END EC PRIVATE KEY-----
"
OK
```

Save device certificate and key contents into two files.

Now use the AWS CLI to register the device certificate onto AWS IoT:

```
C:> aws iot register-certificate --certificate-pem file://client.crt --status
ACTIVE --ca-certificate-pem file://test-ca.pem
{
    "certificateArn": "arn:aws:iot:eu-central-
1:27<...>24:cert/1197abb702b07797c4<...>46efd75965",
    "certificateId": "1197abb702b07797c4<...>46efd75965"
}
```

By visiting the AWS IoT web console, we can now see that an entry appeared in the Certificates section:



(Step 7) Create a Thing on AWS IoT for your device and associate the device certificate to it.

```
C:> aws iot create-thing --thing-name Thing1
{
    "thingArn": "arn:aws:iot:eu-central-1:274183790524:thing/Thing1",
    "thingName": "Thing1",
    "thingId": "b442b530-291e-4bb6-bf18-3212c34024d0"
}
```

To associate the device certificate to the newly created Thing use the following command specifying the Thing name and the device certificate's ARN:

```
C:> aws iot attach-thing-principal --thing-name Thing1 --principal arn:aws:iot:eu-
central-1:27<...>24:cert/1197abb702b07797c4<...>46efd75965
```

In order for your device to communicate with AWS IoT you need to create a security Policy on AWS IoT and attach it to your Thing. For example, a Policy that allows the device to communicate with the AWS Message Broker is as follows (substitute your AWS ID in the Resource fields):

```
{
  "Version": "2012-10-17",
  "Statement": [
    {
      "Effect": "Allow",
      "Action": [
        "iot:Publish",
        "iot:Receive"
      ],
      "Resource": "arn:aws:iot:eu-central-1:27<...>24:topic/test/topic"
    },
    {
      "Effect": "Allow",
      "Action": "iot:Subscribe",
      "Resource": "arn:aws:iot:eu-central-1:27<...>24:topicfilter/test/topic"
    },
    {
      "Effect": "Allow",
      "Action": "iot:Connect",
      "Resource": "arn:aws:iot:eu-central-1:27<...>24:client/test-*"
    }
  ]
}
```

You can create a Policy directly from the AWS IoT web console, by selecting your Thing and following the menus.

Now attach the Policy to your Thing:

```
C:\userdata\sandbox\ZTP>aws iot attach-policy --policy-name "ubxaecel-iot-policy" -
-target "arn:aws:iot:eu-central-1:
27<...>24:cert/1197abb702b07797c4<...>46efd75965"
```

At this point your device is ready to communicate with AWS IoT via any external client.

Appendix

A Glossary

Abbreviation	Definition
APN	Access point Namen
DeviceProfileUID	Equivalent to a model number and can be used to identify a group of similar devices
DTLS	Datagram transport layer security
E2E	End-to-end
IoT	Internet of Things
IT	Information technology
KMS	Key management service
PSK	Pre-shared keys
RAT	Radio access technology
REST API	Representational state transfer application programming interface. Representational state transfer is a software architectural style that defines a set of constraints to be used for creating web services.
RoT	Root of trust
SE	Secure element
Swagger	Set of open-source tools built around the OpenAPI specification for designing, building, documenting and consuming REST APIs
TEE	Trusted execution environment
TLS	Transport layer security
YAML	A human-readable data-serialization language. It is commonly used for configuration files and in applications where data is being stored or transmitted.
u-blox Thingstream	Service and account management platform
IoT Security-as-a-Service	Suite of the u-blox security services
ISEP	A component of u-blox Thingstream platform
CSP	A component of u-blox Thingstream platform

Table 1: Explanation of the abbreviations and terms used

Related documents

[1] SARA-R4 series data sheet, UBX-16029218
[2] SARA-R4 AT commands manual, UBX-17003787
[3] SARA-R4 series system integration manual, UBX-16029218
[4] SARA-R4 application development guide, UBX-18019856
[5] FW update application note, UBX-17049154
[6] curl programming, TUTORIAL

☞ For regular updates to u-blox documentation and to receive product change notifications, register on our homepage (www.u-blox.com).

☞ u-blox services webpage: https://www.u-blox.com/en/services

☞ u-blox services support email: thingstream-support@u-blox.com

Revision history

Revision	Date	Name	Comments
R01	18-Oct-2019	mace	Initial release
R02	22-Jan-2020	amer	Extended document applicability to SARA-R5 series and other functionality enhancements
R03	30-Apr-2020	hsia	Renaming some of parameters and some extension to PSK section.
R04	14-May-2020	hsia	Structural modification
R05	22-May-2020	hsia	Examples
R06	05-Oct-2020	hsia	Extended document on chip-to-chip and Zero touch provisioning (ZTP)

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