User manual

Getting started with the X-CUBE-SAFEA1 software package

Introduction

This user manual describes how to get started with the X-CUBE-SAFEA1 software package.

The X-CUBE-SAFEA1 software package is a software component that provides several demonstration codes, which use the STSAFE-A110 device features from a host microcontroller.

These demonstration codes utilize the STSAFE-A1xx middleware built on the STM32Cube software technology to ease portability across different STM32 microcontrollers. In addition, it is MCU-agnostic for portability to other MCUs.

These demonstration codes illustrate the following features:

- Authentication
- Key generation
- Key establishment
- Signature session
- Local envelope wrapping

1 General information

The X-CUBE-SAFEA1 software package is a reference to integrate the STSAFE-A110 secure element services into a host MCU's operating system (OS) and its application.

It contains the STSAFE-A110 driver and demonstration codes to be executed on STM32 32-bit microcontrollers based on the Arm® Cortex®-M processor.

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The X-CUBE-SAFEA1 software package is developed in ANSI C. Nevertheless, the platform-independent architecture allows easy portability to a variety of different platforms.

The table below presents the definition of acronyms that are relevant for a better understanding of this document.

Table 1. **List of acronyms**

Term	Definition
AES	Advanced encryption standard
ANSI	American National Standards Institute
API	Application programming interface
BSP	Board support package
CA	Certification authority
CC	Common Criteria
ECC	Elliptic curve cryptography
ECDH	Elliptic curve Diffie-Hellman
ECDHE	Elliptic curve Diffie-Hellman ephemeral
EWARM	IAR Embedded Workbench® for Arm®
HAL	Hardware abstraction layer
IDE	Integrated development environment
I²C	Inter-integrated circuit
IoT	Internet of things
LL	Low-level drivers
MAC	Message authentication code
MCU	Microcontroller unit
MDK-ARM	Keil® microcontroller development kit for Arm®
MPU	Memory protection unit
OS	Operating system
SE	Secure element
SHA	Secure hash algorithm
SLA	Software license agreement
TLS	Transport layer security
USB	Universal serial bus

2 STSAFE-A110 secure element

The STSAFE-A110 is a highly secure solution that acts as a secure element providing authentication and data management services to a local or remote host. It consists of a full turnkey solution with a secure operating system running on the latest generation of secure microcontrollers.

The STSAFE-A110 can be integrated in IoT (Internet of things) devices, smart-home, smart-city and industrial applications, consumer electronics devices, consumables and accessories. Its key features are:

- Authentication (of peripherals, IoT and USB Type-C devices)
- Secure channel establishment with remote host including transport layer security (TLS) handshake
- Signature verification service (secure boot and firmware upgrade)
- Usage monitoring with secure counters
- Pairing and secure channel with host application processor
- Wrapping and unwrapping of local or remote host envelopes
- On-chip key pair generation

Refer to the STSAFE-A110 datasheet available on the STSAFE-A110 web page for additional information on the device.

3 STSAFE-A1xx middleware description

This section details the STSAFE-A1xx middleware software package content and the way to use it.

3.1 General description

The STSAFE-A1xx middleware is a set of software components designed to:
- interface the STSAFE-A110 secure element device with an MCU
- implement the most generic STSAFE-A110 use cases

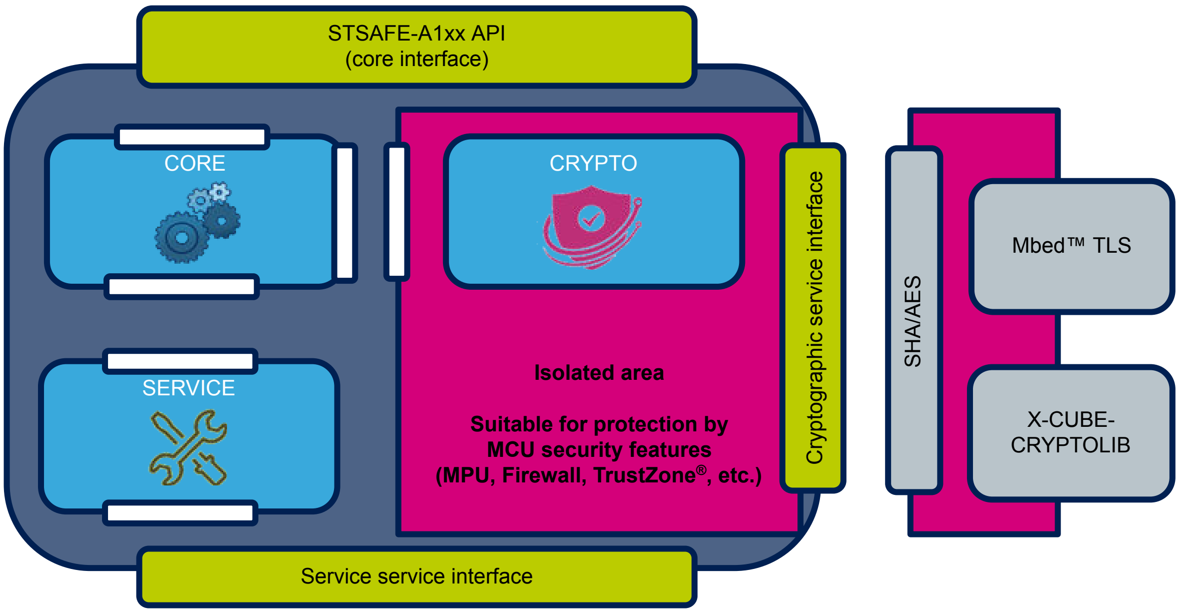
The STSAFE-A1xx middleware is fully integrated within ST software packages as a middleware component to add secure element features (for example X-CUBE-SBSFU or X-CUBE-SAFEA1).
It can be downloaded from the STSAFE-A110 internet page through the **Tools & Software** tab.
The software is provided as source code under an ST software license agreement (SLA0088) (see License information for more details).
The following integrated development environments are supported:
- IAR Embedded Workbench® for Arm® (EWARM)
- Keil® Microcontroller Development Kit (MDK-ARM)
- STM32Cube IDE (STM32CubeIDE)
- System Workbench for STM32 (SW4STM32)

Refer to the release notes available in the package root folder for information about the supported IDE versions.

3.2 Architecture

This section describes the software components of the STSAFE-A1xx middleware software package.
The figure below presents a view of the STSAFE-A1xx middleware architecture and related interfaces.

Figure 1. STSAFE-A1xx middleware architecture


STSAFE-A1xx API
(core interface)
CORE
CRYPTO
SERVICE
Isolated area
Suitable for protection by MCU security features (MPU, Firewall, TrustZone®, etc.)
Cryptographic service interface
SHA/AES
Mbed™ TLS
X-CUBE-CRYPTOLIB
Service service interface

The middleware features three different interfaces:

- **STSAFE-A1xx API:** It is the main application programming interface (API), which provides full access to all the STSAFE-A110 services exported to the upper layers (application, libraries and stacks). This interface is also referred to as the core interface because all the exported APIs are implemented in the CORE module. The upper layers that need to integrate the STSAFE-A1xx middleware must access the STSAFE-A110 features through this interface.
- **Hardware service interface:** This interface is used by the STSAFE-A1xx middleware to reach the highest hardware platform independence. It includes a set of generic functions to connect the specific MCU, IO bus and timing functions. This structure improves the library code re-usability and guarantees easy portability to other devices.

  Defined as weak functions, these generic functions must be implemented at application level following the example provided within the *stsafea_service_interface_template.c* template provided for easy integration and customization within the upper layers.
- **Cryptographic service interface:** This interface is used by the STSAFE-A1xx middleware to access platform or library cryptographic functions such as SHA (secure hash algorithm) and AES (advanced encryption standard) required by the middleware for some demonstrations.

  Defined as weak functions, these cryptographic functions must be implemented at application level following the example provided with two different templates:
  - *stsafea_crypto_mbedtls_interface_template.c* if the Arm® Mbed™ TLS cryptographic library is used;
  - *stsafea_crypto_stlib_interface_template.c* if the ST cryptographic library is used;
- Alternative cryptographic libraries can be used by simply customizing the template source files. The template files are provided for easy integration and customization within the upper layers.

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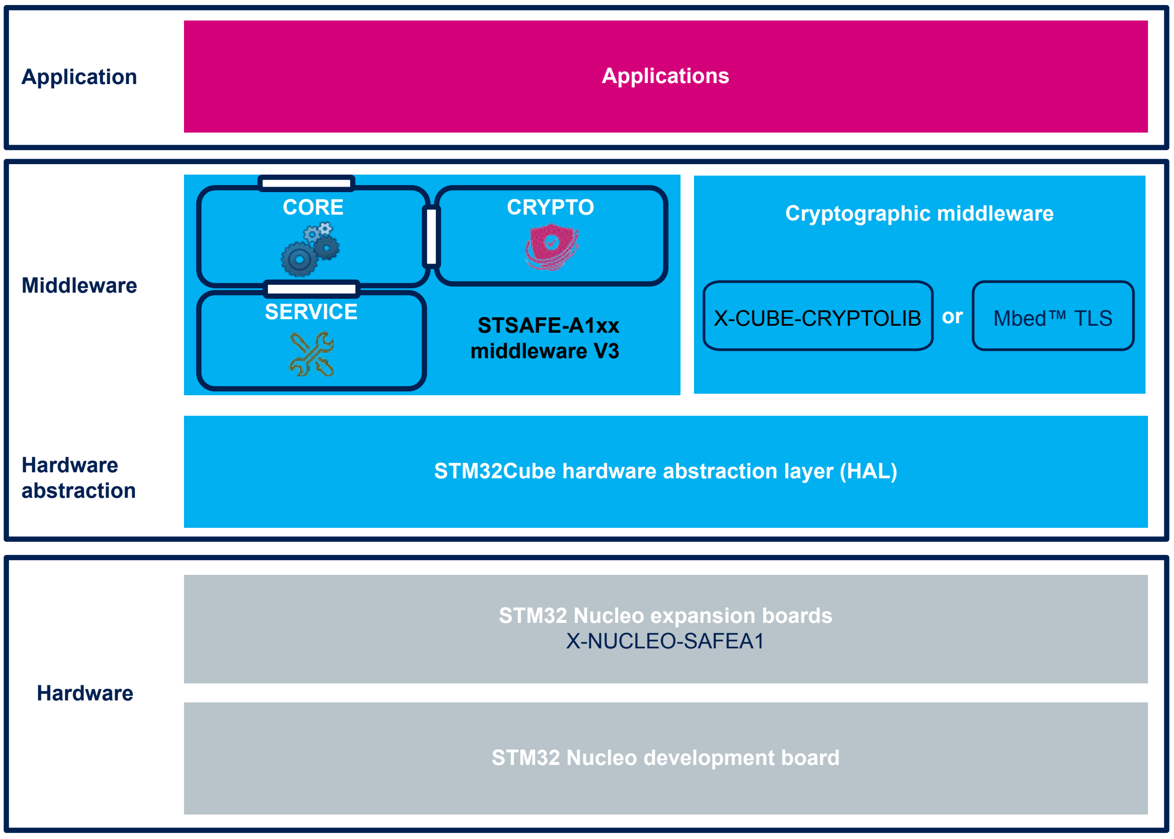
Some examples of application integrating and using the STSAFE-A1xx middleware (such as X-CUBE-SBSFU or X-CUBE-SAFEA1) are based on the STM32Cube hardware abstraction layer (HAL) for STM32 microcontrollers.

The figure below shows the STSAFE-A1xx middleware integrated in a standard STM32Cube application, running on an X-NUCLEO-SAFEA1 expansion board mounted on an STM32 Nucleo board.

Figure 2. STSAFE-A1xx middleware in an STM32Cube application



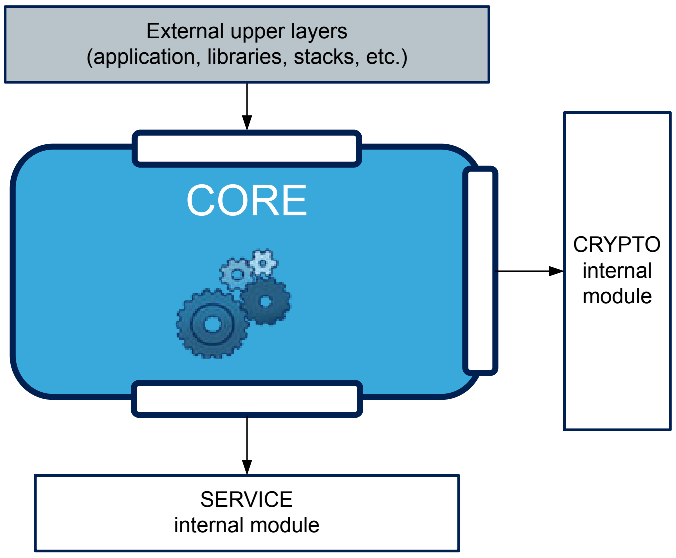
To provide the best hardware and platform independence, the STSAFE-A1xx middleware is not directly connected to the STM32Cube HAL, but through interface files implemented at application level (*stsafea_service_interface_template.c, stsafea_interface_conf.h*).

3.3 CORE module

The CORE module is the core of the middleware. It implements the commands called by the upper layers (application, libraries, stack and so on) in order to properly use the STSAFE-A1xx features.

The figure below presents a view of the CORE module architecture.

Figure 3. **CORE module architecture**



The CORE module is a multi-interface software component connected to:

- Upper layers: external connection through the exported APIs described in the two tables below;
- Cryptographic layer: internal connection to the CRYPTO module;
- Hardware service layer: internal connection to the SERVICE module;

The STSAFE-A1xx middleware software package provides a complete API documentation of the CORE module in the root folder (see *STSAFE-A1xx_Middleware.chm* file).

Refer to the STSAFE-A110 datasheet for a brief explanation of the command set, to which the command APIs listed in the following table are related.

Table 2. **CORE module exported API**

API category	Function
Initialization configuration	**StSafeA_Init** *To create, initialize and assign the STSAFE-A1xx device handle.*
General-purpose commands	**StSafeA_GetVersion** *To return the STSAFE-A1xx middleware revision.*
	StSafeA_Echo *To receive the data passed in the command.*
	StSafeA_Reset *To reset the volatile attributes to their initial values.*
	StSafeA_GenerateRandom *To generates a number of random bytes.*
	StSafeA_Hibernate *To put the STSAFE-Axxx device in hibernation.*

API category	Function
Data partition commands	**StSafeA_DataPartitionQuery** *Query command to retrieve the data partition configuration.*
	StSafeA_Decrement *To decrement the one-way counter in a counter zone.*
	StSafeA_Read *To read data from a data partition zone.*
	StSafeA_Update *To update data through zone partition.*
Private and public key commands	**StSafeA_GenerateKeyPair** *To generate a key-pair in a private key slot.*
	StSafeA_GenerateSignature *To return the ECDSA signature over a message digest.*
	StSafeA_VerifyMessageSignature *To verify the message authentication.*
	StSafeA_EstablishKey *To establish a shared secret between two hosts by using asymmetric cryptography.*
Administrative commands	**StSafeA_ProductDataQuery** *Query command to retrieve the product data.*
	StSafeA_I2cParameterQuery *Query command to retrieve the I²C address and low-power mode configuration.*
	StSafeA_LifeCycleStateQuery *Query command to retrieve the lifecycle state (Born, Operational, Terminated, Born and Locked or Operational and Locked).*
	StSafeA_HostKeySlotQuery *Query command to retrieve the host key information (presence and host C-MAC counter).*
	StSafeA_PutAttribute *To put attributes in the STSAFE-Axxx device, such as keys, password, I²C parameters according to the attribute TAG.*
	StSafeA_DeletePassword *To delete the password from its slot.*
	StSafeA_VerifyPassword *To verify the password and remember the outcome of the verification for future command authorization.*
	StSafeA_RawCommand *To execute a raw command and receive the related response.*
Local envelope commands	**StSafeA_LocalEnvelopeKeySlotQuery** *Query command to retrieve local envelope key information (slot number, presence and key length) for the available key slots.*
	StSafeA_GenerateLocalEnvelopeKey *To generate a key in a local envelope key slot.*
	StSafeA_WrapLocalEnvelope *To wrap data (usually keys) that are entirely managed by the host, with a local envelope key and the [AES key wrap] algorithm.*
	StSafeA_UnwrapLocalEnvelope

API category	Function
Local envelope commands	*To unwrap a local envelope with a local envelope key.*

Table 3. **Exported STSAFE-A110 CORE module APIs**

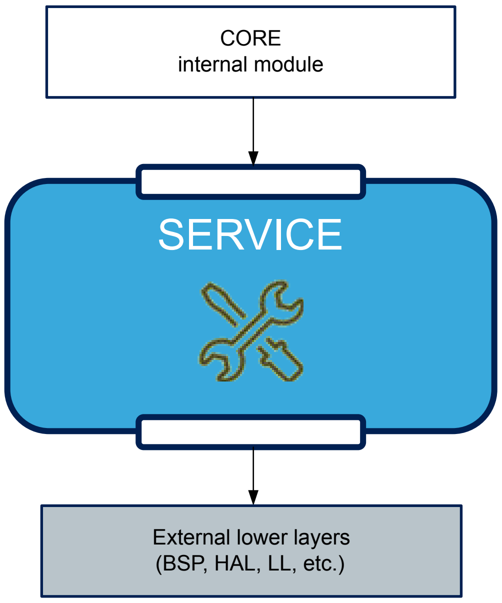
API category	Function
Command authorization configuration command	**StSafeA_CommandAuthorizationConfigurationQuery** *Query command to retrieve access conditions for commands with configurable access conditions.*

3.4 SERVICE module

The SERVICE module is the low layer of the middleware. It implements a full hardware abstraction in terms of MCU and hardware platform.

The figure below presents a view of the SERVICE module architecture.

Figure 4. **SERVICE module architecture**



The SERVICE module is a dual-interface software component connected to:

- External lower layers: such as BSP, HAL or LL. Weak functions must be implemented at external higher layers and are based on the *stsafea_service_interface_template.c* template file;
- Core layer: internal connection to the CORE module through the exported APIs described in the table below;

The STSAFE-A1xx middleware software package provides a complete API documentation of the SERVICE module in the root folder (see *STSAFE-A1xx_Middleware.chm* file).

Table 4. **SERVICE module exported APIs**

API category	Function
Initialization configuration	**StSafeA_BSP_Init** *To initialize the communication bus and the IO pins needed to operate the STSAFE-Axxx device.*
Low-level operation functions	**StSafeA_Transmit** *To prepare the command to be transmitted, and call the low-level bus API to be executed. Compute and concatenate a CRC, if supported.*
	StSafeA_Receive *To receive data from the STSAFE-Axxx by using the low-level bus functions to retrieve them.Check the CRC, if supported.*

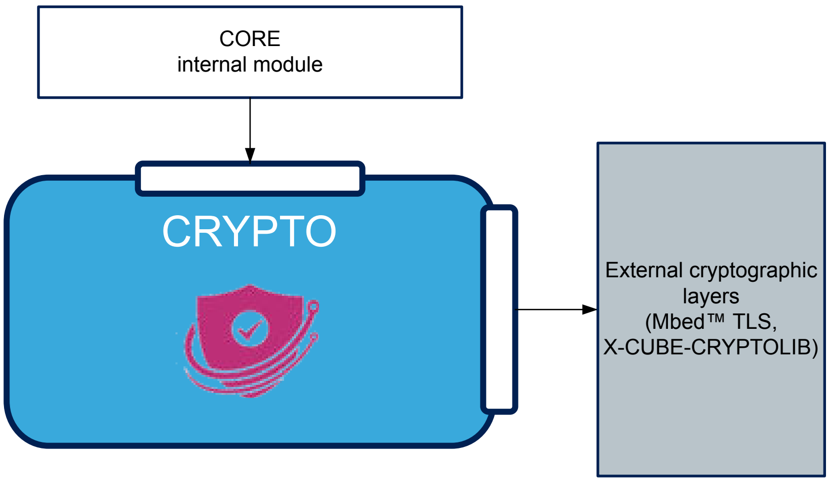
3.5 CRYPTO module

The CRYPTO module represents the cryptographic part of the middleware. It must rely on the platform's cryptographic resources.

The CRYPTO module is completely independent of the other middleware modules and, for this reason, can be easily encapsulated inside an isolated secure area suited to protection by MCU security features such as a memory protection unit (MPU), a firewall or a TrustZone®.

The figure below presents a view of the CRYPTO module architecture.

Figure 5. **CRYPTO module architecture**



The CRYPTO module is a dual-interface software component connected to:

- an external cryptography library: Mbed TLS and X-CUBE-CRYPTOLIB are currently supported. Weak functions must be implemented at external higher layers and are based on the:
  – *stsafea_crypto_mbedtls_interface_template.c* template file for the Mbed TLS cryptographic library;
  – *stsafea_crypto_stlib_interface_template.c* template file for the ST cryptographic library;

    Additional cryptographic libraries can be easily supported by adapting the cryptographic interface template file.
- the core layer: internal connection to the CORE module through the exported APIs described in the table below;

The STSAFE-A1xx middleware software package provides a complete API documentation of the CRYPTO module in the root folder (see *STSAFE-A1xx_Middleware.chm* file).

Table 5. **CRYPTO module exported APIs**

API category	Function
Cryptographic APIs	**StSafeA_InitHASH** *SHA initialization. Used for the STSAFE-A1xx signature session.*
	StSafeA_ComputeHASH *To compute the HASH value. Used for the STSAFE-A1xx signature session.*
	StSafeA_ComputeCMAC *To compute the CMAC value. Used on the prepared command.*
	StSafeA_ComputeRMAC *To compute the RMAC value. Used on the received response.*
	StSafeA_DataEncryption *To execute data encryption (AES CBC) on the STSAFE-Axxx data buffer.*
	StSafeA_DataDecryption *To execute data decryption (AES CBC) on the STSAFE-Axxx data buffer.*
	StSafeA_MAC_SHA_PrePostProcess *To pre- or post-process the MAC and/or SHA before transmission, or after reception of data from the STSAFE_Axxx device.*

3.6 Templates

This section gives a detail description of the templates available within the STSAFE-A1xx middleware software package.

All the templates listed in the table below are provided inside the `Interface` folder available at the root level of the middleware software package.

Template files are provided as examples to be copied and customized into the upper layers, in order to easily integrate and configure the STSAFE-A1xx middleware:

- Interface template files provide example implementations of the __*weak* functions, offered as empty or partially empty functions inside the middleware. They must be properly implemented in the user space or in the upper layers according to the cryptographic library and to the user's hardware choices.
- Configuration template files provide an easy way to configure the STSAFE-A1xx middleware and features that can be used in the user application, such as optimizations or specific hardware.

Table 6. **Templates**

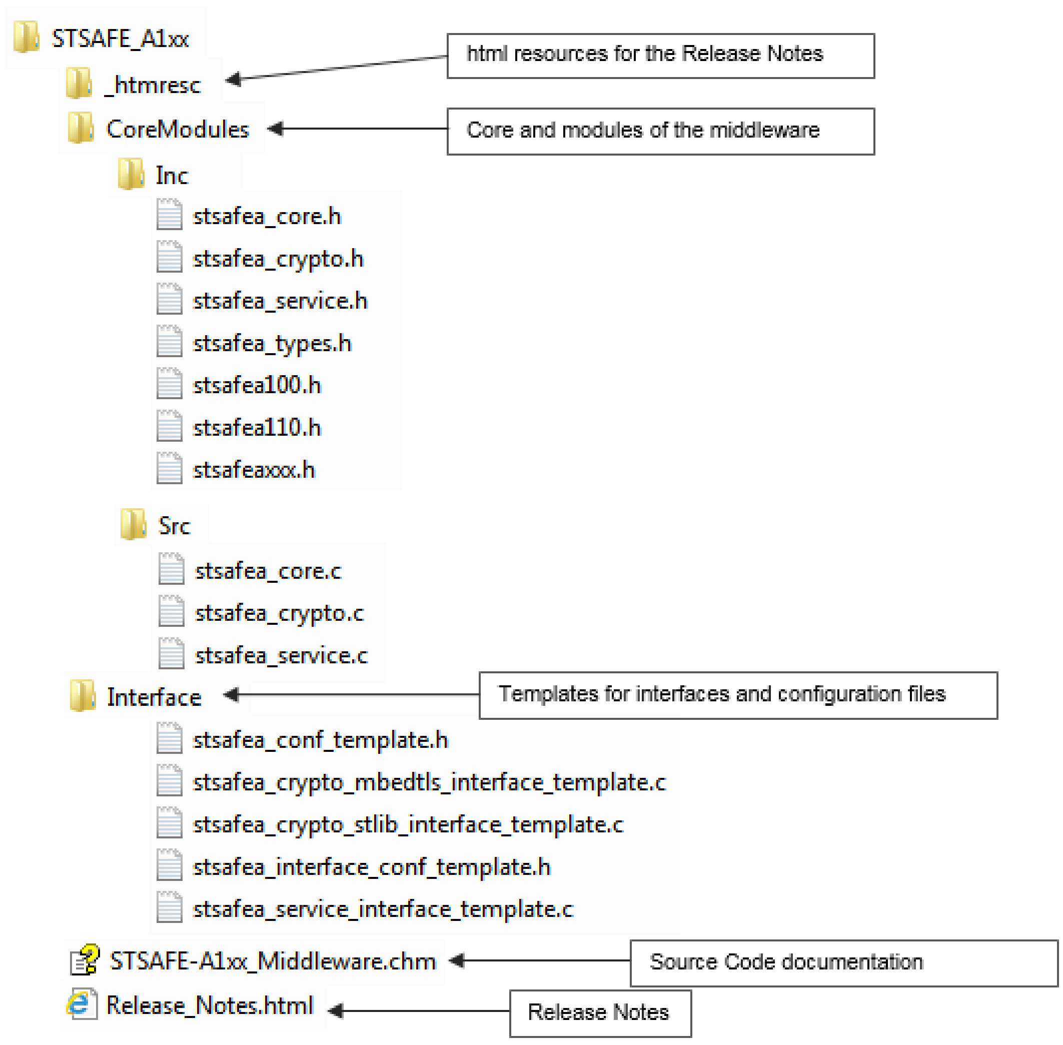
Template category	Template file
Interface templates	**stsafea_service_interface_template.c** *Example template to show how to support the hardware services required by the STSAFE-A middleware and offered by the specific hardware, low-level library or BSP selected in the user space.*
	stsafea_crypto_mbedtls_interface_template.c *Example template to show how to support the cryptographic services required by the STSAFE-A middleware and offered by the Mbed TLS cryptographic library (key management, SHA, AES, etc.).*
	stsafea_crypto_stlib_interface_template.c *Example template to show how to support the cryptographic services required by the STSAFE-A middleware and offered by the STM32 cryptographic library software expansion for STM32Cube (X-CUBE-CRYPTOLIB) (key management, SHA, AES, etc.).*
Configuration templates	**stsafea_conf_template.h** *Example template to show how to configure the STSAFE-A middleware (in particular for optimizations purposes).*

Template category	Template file
Configuration templates	**stsafea_interface_conf_template.h** *Example template to show how to configure and customize the interface files listed above.*

3.7 Folder structure

The figure below presents the folder structure of the STSAFE-A1xx middleware software package.

Figure 6. **Project file structure**


STSAFE_A1xx
_htmresc
html resources for the Release Notes
CoreModules
Core and modules of the middleware
Inc
stsafea_core.h
stsafea_crypto.h
stsafea_service.h
stsafea_types.h
stsafea100.h
stsafea110.h
stsafeaxxx.h
Src
stsafea_core.c
stsafea_crypto.c
stsafea_service.c
Interface
Templates for interfaces and configuration files
stsafea_conf_template.h
stsafea_crypto_mbedtls_interface_template.c
stsafea_crypto_stlib_interface_template.c
stsafea_interface_conf_template.h
stsafea_service_interface_template.c
STSAFE-A1xx_Middleware.chm
Source Code documentation
Release_Notes.html
Release Notes

3.8 How to: integration and configuration

This section describes how to integrate and configure the STSAFE-A1xx middleware in the user application.

3.8.1 Integration steps

Follow these steps to integrate the STSAFE-A1xx middleware in the desired application:

- Step 1: Copy (and optionally rename) the *stsafea_service_interface_template.c* file and either of *stsafea_crypto_mbedtls_interface_template.c* or *stsafea_crypto_stlib_interface_template.c* to the user space according to the cryptographic library that has been added to the application (whatever the cryptographic library selected/used by users, they can even create/implement their own cryptographic interface file from scratch by adapting the suitable template).
- Step 2: Copy (and optionally rename) the *stsafea_conf_template.h* and *stsafea_interface_conf_template.h* files to the user space.
- Step 3: Make sure to add the right includes in your main or any other user space source file that needs to interface the STSAFE-A1xx middleware:
  `#include "stsafea_core.h" #include "stsafea_interface_conf.h"`
- Step 4: Customize the files used in the three steps above according to user preferences.

3.8.2 Configuration steps

In order to properly configure the STSAFE-A1xx middleware in the user application, ST provide two different configuration template files to be copied and customized in the user space according to the user's choices:

- *stsafea_interface_conf_template.h*: This example template is used to and shows how to configure the cryptographic and service middleware interfaces in the user space through the following `#define` statements:
  – `USE_PRE_LOADED_HOST_KEYS`
  – `USE_SIGNATURE_SESSION`
  – `MCU_PLATFORM_INCLUDE`
  – `MCU_PLATFORM_BUS_INCLUDE`
- *stsafea_conf_template.h*: This example template is used to and shows how to configure the STSAFE-A middleware through the following `#define` statements:
  – `STSAFEA_USE_OPTIMIZATION_SHARED_RAM`
  – `STSAFEA_USE_OPTIMIZATION_NO_HOST_MAC`
  – `STSAFEA_USE_OPTIMIZATION_CRC_TABLE`
  – `STSAFEA_USE_FULL_ASSERT`

Follow these steps in order to integrate the STSAFE-A1xx middleware in the desired application:

- Step 1: Copy (and optionally rename) the *stsafea_interface_conf_template.h* and *stsafea_conf_template.h* files to the user space.
- Step 2: Confirm or modify the `#define` statement of the two above-mentioned header files according to the user platform and cryptographic choices.

4 Demonstration software

This section illustrates demonstration software based on the STSAFE-A1xx middleware.

4.1 Authentication

This demonstration illustrates the command flow where the STSAFE-A110 is mounted on a device that authenticates to a remote host (IoT device case), the local host being used as a pass-through to the remote server.

The scenario where the STSAFE-A110 is mounted on a peripheral that authenticates to a local host, for example for games, mobile accessories or consumables, is exactly the same.

Command flow

Note: For demonstration purposes, the local and remote hosts are the same device here.

1. Extract, parse and verify the STSAFE-A110's public certificate stored in the data partition zone 0 of the device in order to get the public key:
   – Read the certificate using the STSAFE-A1xx middleware through the STSAFE-A110's zone 0.
   – Parse the certificate using the cryptographic library's parser.
   – Read the CA certificate (available through the code).
   – Parse the CA certificate using the cryptographic library's parser.
   – Verify the certificate validity using the CA certificate through the cryptographic library.
   – Get the public key from the STSAFE-A110 X509 certificate.
2. Generate and verify the signature over a challenge number:
   – Generate a challenge number (random number).
   – Hash the challenge.
   – Fetch a signature over the hashed challenge using the STSAFE-A110's private key slot 0 through the STSAFE-A1xx middleware.
   – Parse the generated signature using the cryptographic library.
   – Verify the generated signature using the STSAFE-A110's public key through the cryptographic library.
   – When this is valid, the host knows that the peripheral or IoT is authentic.

4.2 Pairing

This code example establishes a pairing between an STSAFE-A110 device and the MCU it is connected to. The pairing allows the exchanges between the device and the MCU to be signed and verified. The STSAFE-A110 device becomes usable only in combination with the MCU it is paired with. Both host keys are stored to the Flash memories of the STM32 and STSAFE-A110.

The code example also generates a local envelope key when this is not already populated in the STSAFE-A110.

These keys are used to:

- wrap/unwrap a local envelope
- execute commands requiring a C-MAC and/or payload encryption

Note: The pairing code example must be executed successfully prior to executing all the following code examples.

Command flow

1. Generate the local envelope key in the STSAFE-A110 using the STSAFE-A1xx middleware.
   This operation occurs only if the STSAFE-A110's local envelope key slot is not already populated.
2. Generate two 128-bit random numbers to use as the host MAC key and the host cipher key.
3. Store the host MAC key and the host cipher key to their respective slot in the STSAFE-A110.
4. Store the host MAC key and the host cipher key to the STM32's Flash memory.

4.3 Key establishment

This demonstration illustrates the case where the STSAFE-A110 device is mounted on a device (such as an IoT device), which communicates with a remote server and needs to establish a secure channel to exchange data with it.

The goal of this use case is to establish a shared secret between the local host and the remote server using the elliptic curve Diffie-Hellman scheme with a static (ECDH) or ephemeral (ECDHE) key in the STSAFE-A110.

The shared secret should be further derived to one or more working keys (not illustrated here). The working keys can then be used in communication protocols such as TLS, for example for protecting the confidentiality, integrity and authenticity of the data that are exchanged between the local host and the remote server.

Command flow

Note: The local and remote hosts are the same device here.

1. Generate an ephemeral key pair using the STSAFE-A110's middleware.
   The private key is generated through the STSAFE-A110's ephemeral key slot.
   A key pair can be used only once.
2. Import the generated ephemeral public key using the cryptographic library middleware.
3. Import the host's private key using the cryptographic library middleware.
4. Compute the host's secret (host's private key * STSAFE-A110's ephemeral public key) using the cryptographic library middleware.
5. Parse the host's public certificate to get the host's public key.
6. Compute the STSAFE-A110's secret (host's public key * STSAFE-A110's ephemeral private key) using the STSAFE-A110's middleware.
7. Compare the host's secret to the STSAFE-A110's secret. They should be equal.
   The secret can be used as a static key to encrypt/decrypt data to be transmitted.

4.4 Wrap/unwrap local envelopes

This demonstration illustrates the case where the STSAFE-A110 wraps/unwraps the local envelope in order to securely store a secret to any non-volatile memory (NVM).

Encryption/decryption keys can be securely stored in that manner to additional memory or within the STSAFE-A110's user data memory.

The wrapping mechanism is used to protect a secret or plain text. The output of wrapping is an envelope encrypted with an AES key wrap algorithm, and that contains the key or plain text to be protected.

Command flow

Note: The local and remote hosts are the same device here.

1. Generate random data assimilated to a local envelope.
2. Wrap the local envelope using the STSAFE-A110's middleware.
3. Store the wrapped envelope.
4. Unwrap the wrapped envelope using the STSAFE-A110's middleware.
5. Compare the unwrapped envelope to the initial local envelope. They should be equal.

Revision history

Table 7. **Document revision history**

Date	Revision	Changes
09-Dec-2019	1	Initial release.
13-Jan-2020	2	Removed *Licence information* section.

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