Linux on IBM Z and LinuxONE

# *libica Programmer's Reference Version 4.2*

SC34-2602-15

**Note**

Before using this document, be sure to read the information in "Notices" on page 199.

**Edition notice**

This edition applies to libica version 4.2 for openCryptoki version 3.19 and to all subsequent releases and modifications until otherwise indicated in new editions.

# Contents

# About this document

This document describes how to install and use the current version of the Library for IBM® Cryptographic Architecture (libica).

libica is a library of cryptographic functions used to write cryptographic applications on Linux® on IBM Z and LinuxONE, both with and optionally without cryptographic hardware exploitation.

You can find the latest version of this document on the IBM Documentation at:

https://www.ibm.com/docs/en/linux-on-systems?topic=overview-libica-programmers-reference

## How this document is organized

The information is divided into topics that describe installing, configuring and using libica together with descriptions of the functions and example programs.

Chapter 1, "General information about libica," on page 1 has general information about the current libica version.

Chapter 2, "Installing and using libica," on page 5 contains installation and set up instructions, and coexistence information for the current libica version.

Chapter 3, "Application programming interfaces ," on page 11 describes the APIs of the libica cryptographic functions.

Chapter 4, "libica constants, type definitions, data structures, and return codes," on page 133 lists the defines, typedefs, structs, and return codes for libica.

Chapter 5, "libica tools," on page 139 contains tools to investigate the capabilities of your cryptographic hardware and how these capabilities are used by applications that use libica.

Chapter 6, "Examples," on page 149 is a set of programming examples that use the libica APIs.

## Who should read this document

This document is intended for C programmers who want to access IBM Z® hardware support for cryptographic methods.

In particular, this publication addresses programmers who write hardware-specific plug-ins for cryptographic libraries such as OpenSSL and openCryptoki.

## Distribution independence

This publication does not provide information that is specific to a particular Linux distribution.

The tools it describes are distribution independent.

## Other publications for Linux on IBM Z and LinuxONE

You can find publications for Linux on IBM Z and LinuxONE on IBM Documentation.

These publications are available on IBM Documentation at ibm.com/docs/en/linux-on-systems?topic=linuxone-library-overview

- *Device Drivers, Features, and Commands*
- *Using the Dump Tools*
- *How to use FC-attached SCSI devices with Linux on z Systems®*, SC33-8413
- *Networking with RoCE Express*, SC34-7745

- *KVM Virtual Server Management*, SC34-2752
- *Configuring Crypto Express Adapters for KVM Guests*, SC34-7717
- *Introducing IBM Secure Execution for Linux*, SC34-7721
- *openCryptoki - An Open Source Implementation of PKCS #11*, SC34-7730
- *libica Programmer's Reference*, SC34-2602
- *libzpc - A Protected-Key Cryptographic Library*, SC34-7731
- *Exploiting Enterprise PKCS #11 using openCryptoki*, SC34-2713
- *Secure Key Solution with the Common Cryptographic Architecture Application Programmer's Guide*, SC33-8294
- *Pervasive Encryption for Data Volumes*, SC34-2782
- *Enterprise Key Management for Pervasive Encryption of Data Volumes*, SC34-7740
- *How to set an AES master key*, SC34-7712
- *Troubleshooting*, SC34-2612
- *Kernel Messages*, SC34-2599
- *How to Improve Performance with PAV*, SC33-8414
- *How to Set up a Terminal Server Environment on z/VM*, SC34-2596

# Summary of changes

This revision reflects changes to the Development stream for libica version 4.2.

You can find the open source version of libica at:

```
https://github.com/opencryptoki/libica/releases
```

## Updates for libica versions 4.1 and 4.2

### Edition SC34-2602-15

The current libica versions 4.1 and 4.2 provide the following new features:

- The libica library is enabled for FIPS 140-3 compliance. Whether or not an instance of libica that uses OpenSSL, can be successfully certified for the FIPS 140-3 level, depends on the Linux distribution and the version or the distribution-specific variant of OpenSSL that this instance of libica links to. This documentation describes the changes in behavior of libica.
- The following new functions are provided:
  - Function `ica_aes_xts_ex()` supports multi-part operations.
  - Use function `ica_ecdsa_sign_ex()` to create a deterministic ECDSA signature for a given hash data using an ECC key object and a known value k. This allows to implement known-answer tests. Therefore, in FIPS mode this function is only allowed for internal self tests, because in FIPS mode, it is not allowed to create deterministic signatures using an external API.
  - A new FIPS-compliant function `ica_aes_gcm_initialize_fips()` has the same purpose as the existing `ica_aes_gcm_initialize()` API, but additionally allows to create the initialization vector internally via an approved random source and pass it back to the application.
  - A new FIPS-compliant function `ica_aes_gcm_kma_init_fips()` has the same purpose as the existing `ica_aes_gcm_kma_init()` API, but creates the initialization vector (IV) for encryption operations internally using an approved random source. This FIPS compliant IV can be obtained with API `ica_aes_gcm_kma_get_iv()` for subsequent decryption operations.
  - Function `ica_get_msa_level()` returns the processor's highest message security assist level (MSA Extension).
  - Function `ica_get_fips_indicator()` returns a FIPS service indicator. That is, for each hardware function or any other mechanism ID, an indication is provided whether this function or mechanism is FIPS-compliant or not.
  - Function `ica_get_build_version()` returns a configurable string to indicate libica build information. This can for example be used by vendors to indicate a special vendor build.
  - Function `ica_get_hw_info()` returns hardware information about the used processor. It is a FIPS requirement to allow applications to unambiguously determine the version of underlying hardware components. The processor information together with the MSA level uniquely identify the CPACF firmware level.
- The **`icainfo`** utility has new options:
  - Use option `-f` to display algorithms or libica mechanisms that are considered to be not FIPS-compliant, but are not blocked. Applications may then decide whether to use an algorithm or mechanism or not.
  - Use option `-r` to display the available RSA key sizes on the current system configuration.
  - Using option `-v` now additionally displays available distribution- or vendor-specific libica build information.

# Updates for libica version 4.0

### Edition SC34-2602-14

The current libica version 4.0 provides the following new features:

- The `libica.so` library module of libica version 4.0 is now built without software fallbacks by default (compile option NO_SW_FALLBACKS). Thus, `libica.so` has the same behavior as `libica-cex.so` related to software fallbacks. This changes the API behavior: applications are now responsible for implementing software fallbacks if desired. CPACF support is still available.

  However, libica can still be built manually with software fallbacks enabled.
- The following deprecated API functions are removed starting with libica version 4.0:

```
ica_des_encrypt           -> use ica_des_ecb() or ica_des_cbc() instead
ica_des_decrypt           -> use ica_des_ecb() or ica_des_cbc() instead
ica_3des_encrypt          -> use ica_3des_ecb() or ica_3des_cbc() instead
ica_3des_decrypt          -> use ica_3des_ecb() or ica_3des_cbc() instead
ica_aes_encrypt           -> use ica_aes_ecb() or ica_aes_cbc() instead
ica_aes_decrypt           -> use ica_aes_ecb() or ica_aes_cbc() instead
```

- The **`icainfo`** utility now shows two additional output lines for RSA_KEY_GEN_ME and RSA_KEY_GEN_CRT.
- With a new option of the **`icastats`** utility, users of libica can now additionally display the usage of AES, RSA, and ECC algorithms on a per-key-size basis. By default, the per-key-size counters are not displayed, only the overall usage of the algorithms.

  Also, there is a new option to output the new per-key-size counters in JSON format.

# Updates for libica version 3.8 and libica version 3.9

### Edition SC34-2602-13

- In FIPS mode, the initial integrity check is now always performed. In the previous libica version 3.7, the check was only performed when a `hmac` file was available. It was assumed that distributions provide their own `hmac` files. Now the creation of `hmac` files using a static default key is part of the `make` process and distributors may or may not specify their own `hmac` key.
- A variant of the `libica.so` module, called `libica-cex.so`, is provided. This module is built without software fallbacks and without any functionality using CPACF. It only provides RSA, ECDSA, and ECDH acceleration via IBM CryptoExpress accelerators and CCA coprocessors. The module is intended to simplify certifications in environments that do not require CPACF acceleration when using libica. A corresponding `icainfo` processing is provided to display the available functions of the `libica-cex` module.
- The **`icainfo`** utility has a new option `-c` to display all elliptic curves that are supported by libica on the current system configuration.
- libica version 3.9 supports OpenSSL version 1.1 and version 3.0. Earlier versions are no longer supported.

# Chapter 1. General information about libica

The libica library provides hardware support by cryptographic coprocessors and CPACF for cryptographic functions.

The cryptographic coprocessors are used for asymmetric cryptographic functions. The CPACF is used for symmetric encryption and decryption, pseudo random number generation, message authentication, secure hashing, and, since IBM z15™ (MSA 9), for EC sign and verify operations. For some of these functions, if the hardware is not available or failed, libica uses the low-level cryptographic functions of OpenSSL, if available.

This product includes software that is developed by the OpenSSL Project for use in the OpenSSL Toolkit (http://www.openssl.org). This product includes cryptographic software that is written by Eric Young (eay@cryptsoft.com).

The libica library is part of the openCryptoki project in GitHub. It is primarily used by OpenSSL through the IBM OpenSSL CA engine or by openCryptoki through the ICA token. A higher level of security can be achieved by using it through the PKCS #11 API implemented by openCryptoki.

The libica library is optimized to work on IBM Z hardware.

IBM reserves the right to change or modify this API at any time. However, an effort is made to keep the API compatible with later versions within a major release.

You can use the **icastats** utility to obtain statistics about cryptographic processes. See "icastats - Show use of libica functions" on page 142 for more information.

libica is an open source project and can be found at:

```
https://github.com/opencryptoki/libica/releases
```

In the extracted source package, you also find test cases for all APIs in directory `/src/tests/`.

## Check the prerequisites: cryptographic device driver and cryptographic coprocessor

To exploit hardware support of most of the asymmetric cryptographic operations, you need a loaded device driver and an installed IBM cryptographic coprocessor.

### Installing and loading the cryptographic device driver

The cryptographic device driver is included in the regular kernel package shipped with your Linux distribution.

To check, enter the **lszcrypt** command:

```
# lszcrypt
CARD.DOMAIN TYPE  MODE        STATUS  REQUESTS
----------------------------------------------
00          CEX5A Accelerator online         0
00.001a     CEX5A Accelerator online         0
01          CEX5C CCA-Coproc  online        55
01.001a     CEX5C CCA-Coproc  online        55
03          CEX5P EP11-Coproc online        50
03.001a     CEX5P EP11-Coproc online        50
04          CEX6A Accelerator online         0
04.001a     CEX6A Accelerator online         0
05          CEX6C CCA-Coproc  online       104
05.001a     CEX6C CCA-Coproc  online       104
06          CEX7P EP11-Coproc online         8
06.001a     CEX7P EP11-Coproc online         8
```

If the following error message is displayed, load the zcrypt device driver main module:

```
error - cryptographic device driver zcrypt is not loaded!
```

In earlier Linux distributions, the cryptographic device driver is shipped as a single module called **z90crypt**. In more recent distributions, the cryptographic device driver is shipped as set of modules with the **ap** module being the main module that triggers loading all required sub-modules. There is, however, an alias name **z90crypt** that links to the **ap** main module.

There might be distributions using kernel levels starting with 4.10, that have basic cryptographic device driver support as part of the kernel (that is, the **ap** module is already compiled in the kernel). In this case, the subsequently mentioned **lsmod** and **modprobe** commands do not work as described. In addition, the **domain** and **poll_thread** parameters are no longer module parameters, but kernel parameters. In this case, you can change the values directly via sysfs, or change as kernel parameters. Refer to the *Device Drivers, Features, and Commands* for upstream kernels for further information.

For installations with a loadable cryptographic device driver, use the **lsmod** command to find out if either the **z90crypt** or the **ap** module is already loaded.

If required, use the **modprobe** command to load the **z90crypt** or **ap** module. When loading the **z90crypt** or **ap** module, you can use the following optional module parameters:

**domain=**

specifies a particular cryptographic domain. By default, the device driver attempts to use the domain with the maximum number of devices.

After loading the device driver, use the **lszcrypt** command with the -b option to confirm that the correct domain is used. If your distribution does not include this command, see the version of *Device Drivers, Features, and Commands* that applies to your distribution about how to use the sysfs interface to find out the domain. This publication also provides more information about loading and configuring the cryptographic device driver.

If the cryptographic device driver is part of the kernel, you cannot unload it. In this case, you can directly edit domain settings via sysfs.

**poll_thread=**

enables the polling thread for instances of Linux on z/VM® and for Linux instances that run in LPAR mode on an IBM Z platform earlier than z10.

For Linux instances that run in LPAR mode on a z10 or later, this setting is ignored and AP interrupts are used instead.

For more information about these module parameters, the polling thread, and AP interrupts, see the version of *Device Drivers, Features, and Commands* that applies to your distribution.

See your Linux distribution documentation for how to load the module persistently.

## Checking the cryptographic adapter availability

Check whether you have plugged in and enabled your IBM cryptographic adapter and validate your model and type configuration (accelerator or coprocessor).

Use the **lszcrypt -V** command to display detailed information about the cryptographic coprocessors:

```
# lszcrypt -V

CARD.DOMAIN TYPE  MODE        STATUS  REQUESTS  PENDING HWTYPE QDEPTH FUNCTIONS  DRIVER
--------------------------------------------------------------------------------------------
0c          CEX7A Accelerator online        46        0     13     08 -MC-A-NF-  cex4card
0c.004c     CEX7A Accelerator online        46        0     13     08 -MC-A-NF-  cex4queue
0f          CEX7C CCA-Coproc  online         4        0     13     08 S--D--NF-  cex4card
0f.004c     CEX7C CCA-Coproc  online         4        0     13     08 S--D--NF-  cex4queue
10          CEX7P EP11-Coproc online         0        0     13     08 -----XNF-  cex4card
10.004c     CEX7P EP11-Coproc online         0        0     13     08 -----XNF-  cex4queue
```

Use the **chzcrypt** command to enable (online state) or disable (offline state) an IBM cryptographic adapter:

```
$ chzcrypt -e 0x06    // set card 06 online
$ chzcrypt -d 0x06    // set card 06 offline
```

For more information about IBM cryptographic coprocessors with Linux on IBM Z and LinuxONE see

```
Drivers, Features, and Commands, SC33-8411.
```

## Accessing libica functions through the PKCS #11 API (openCryptoki)

The cryptographic functions provided by libica can be accessed using the PKCS #11 API implemented by openCryptoki.

For information on how to install and configure openCryptoki, and how to exploit the features of openCryptoki using the ICA token, refer to *openCryptoki - An Open Source Implementation of PKCS #11*.

For a description of the current PKCS #11 standard, see `PKCS #11 Cryptographic Token Interface Standard`.

# Chapter 2. Installing and using libica

View the contained subtopics for information about where to obtain the libica library, and how to install it.

## Installing libica from the distribution packages

To make use of the described libica hardware support for cryptographic functions, it is necessary to install the libica package. Obtain the libica package from your distribution provider as soon as available (RPM or DEB) for package manager installation.

The libica library is available as an RPM or DEB package named `libica4-`*`<version>`* within your distribution package.

Mainly there are two packages, a library package and a development package. Ubuntu and recent SUSE Linux Enterprise Server distributions separated the **`icastats`** and **`icainfo`** utilities into the libica-tools package.

See your Linux distribution documentation for how to install an RPM or DEB package. To check whether the libica library is installed, issue:

```
# rpm -qa | grep -i libica  /* for Redhat and SUSE  */

# dpkg -l | grep -i libica  /* for Ubuntu */
```

## Installing libica from the source package

If you prefer, you can install libica from the source package manually.

### Procedure

1. Download the latest libica sources from the GitHub libica website.
2. Extract the tar archive.

   There should be a new directory named `libica-4.x.x`.
3. Change to that directory and execute the following scripts and commands:

   ```
   # ./bootstrap.sh
   # ./configure
   # make
   # make install
   # make fipsinstall /* optional, only applicable with configure --enable-fips */
   # make check /* optional */
   ```

   where:

   **bootstrap.sh**

   Initial setup, basic configurations

   **configure**

   Check configurations and build the makefile. For detailed information, refer to the INSTALL file from the libica package.

   You can use the option `--enable-fips` when running the **`configure`** command to enable the build environment to compile with FIPS mode:

   ```
   configure --enable-fips
   ```

   libica version 4.1 is compliant to FIPS 140-3. libica versions in the range 3.0 - 4.0 are compliant to FIPS 140-2.

You can use the option --enable-internal-tests when running the **configure** command to enable the internal tests for elliptic curve cryptography:

```
configure --enable-internal-tests
```

With this option, internal tests perform additional algorithm tests on all supported elliptic curves.

**make**
Compile and link

**make install**
Install the libraries

**make fipsinstall**
Install the FIPS HMAC file (only when configured in FIPS mode)

**make check**
Execute the libica tests

# Using libica

The function prototypes are provided in this header file: include/ica_api.h.

Applications using these functions must link to libica and libcrypto. The libcrypto library is available from the OpenSSL package. You must have OpenSSL in order to run programs using the current libica version.

## Using the libica-cex variant

A variant of the libica.so module, called libica-cex.so, is intended to simplify certifications in environments that do not require CPACF acceleration when using libica.

The libica-cex module is built without software fallbacks and without any functionality using CPACF. It only provides RSA, ECDSA, and ECDH acceleration via IBM cryptographic coprocessors.

# Using libica in FIPS mode

To be compliant to the Federal Information Processing Standards (FIPS), an application must adhere to the various data security and computer system requirements outlined in the FIPS standards created by the National Institute of Standards and Technology (NIST).

Out of a multitude of FIPS standards, the FIPS 140 regulations govern the use of cryptographic services. They require that all cryptographic processing performed by US government personnel must be completed using hardware or software that have been independently tested and certified by NIST, to meet the extensive requirements of these FIPS 140 regulations.

Therefore, if you enable the so-called FIPS mode during libica configuration in whatever environment, libica runs according to the highest applied FIPS level, even if not certified in the current environment.

The FIPS 140-1 document was issued in 1994 and withdrawn May 2002. libica version 4.1 is compliant to FIPS 140-3 with documented restrictions. libica versions in the range 3.0 - 4.0 are compliant to FIPS 140-2.

When running in FIPS mode, only cryptographic algorithms approved by the National Institute of Standards and Technology (NIST) can be used.

Also, when running in FIPS mode, an initial integrity check on the libica library file libica.so is performed by calculating an HMAC from that file contents using a HMAC key. This key is specified at two places: in the makefile and in the code (fips.c). At runtime, the HMAC (calculated with the key from fips.c) is then compared with the HMAC (pre-calculated with the key from the makefile) in an existing HMAC file. If the pre-calculated HMAC value is different to the calculated one, an error occurs and any cryptographic operation is blocked. Check your libica installation and ensure that the correct libica.hmac file is installed in the same directory as libica.so. The library and its default distribution location is /usr/lib64/libica.so.

In libica version 3.7, an HMAC file was optional. If no HMAC file was present, `libica.so` could be used without any integrity check performed. Starting with libica version 3.8, a HMAC file is always provided (by default or by the distribution) and the integrity check is always performed.

For information on how to enable or disable the FIPS mode for libica, see "Enabling libica for FIPS mode" on page 8.

The **`icainfo`** output indicates whether libica has built-in FIPS support, whether it is running in FIPS mode, and whether it is in an error state. Algorithms that are not FIPS approved are marked as `blocked` when running in FIPS mode. All algorithms are marked as `blocked` when libica is in an error state.

### Compile option NO_FIPS_CONFIG_LOAD

The compile option NO_FIPS_CONFIG_LOAD allows to skip the loading and reading of the FIPS configuration of OpenSSL 3.0 or later. Distributions must decide whether to use this compile option to adjust the behavior to their needs.

### Environment variable LIBICA_FIPS_FLAG

Use this environment variable to allow to run libica tests in active FIPS mode on systems that are not running in FIPS mode (for example, when the kernel FIPS flag is off). Setting this variable to LIBICA_FIPS_FLAG=1 overrides the kernel's FIPS indication and puts libica into active FIPS mode. Other values than 1 are ignored. In such cases, the FIPS test is skipped, because it would fail due to this discrepancy.

## FIPS 140-2 mode dependencies

Read about the dependencies on software and hardware that exist if you want to run libica versions in the range 3.0 - 4.0 in FIPS 140-2 mode.

In a certain environment, the libica library is certified according to the FIPS 140-2 standard (see NIST Computer Security Resource Center).

The NIST defines so called Federal Information Processing Standards (FIPS). One of their publications, the *FIPS 140-2 Security Requirements For Cryptographic Modules* defines a standard for cryptography-based security systems (crypto modules) used by US Federal organizations to protect sensitive data. FIPS 140-2 certifications are done under the *Cryptographic Module Validation Program (CMVP)*.

The FIPS 140-2 standard specifies four levels of security. Each level corresponds to a set of requirements wherein a higher level is a strict superset of the lower levels. Software cryptographic modules can maximally reach a level 1 certification. In order to make the libica FIPS 140-2 level 1 conformant, the library has been extended by the following features:

- When running in FIPS mode, only NIST approved crypto algorithms can be used and various self-tests are conducted. Approved crypto algorithms are listed in *Annex A: Approved Security Functions for FIPS PUB 140-2*. However, it is possible to disable this feature at compile time. Non-approved algorithms (like for example, DES and PRNG) are disabled when running in FIPS mode.
- Various self-tests required by FIPS 140-2 are implemented. If a self-test fails, libica enters an error state (FIPS error state) and does not perform any cryptographic operations. In this case, an error message is written to the *syslog*.
- The DRBG error state was changed to trigger the FIPS error state. In this case an error message is written to the *syslog*.
- New interfaces were added to enable the consuming application to trigger the self-tests on demand and to query the status (see "FIPS mode functions" on page 115). The status indicates, which self-tests were passed or failed and whether libica is running in FIPS mode.

For detailed information about the FIPS 140-2 standard, see *FIPS PUB 140-2*.

### Dependencies on Open Source software (OpenSSL)

At startup, the library reads the kernel FIPS flag from the `proc` filesystem (see "Enabling the Linux kernel for FIPS mode" on page 8). If the flag is found to be 1, then the libica deterministic random bit generator (DRBG) must be used for random number generation, because the libica PRNG is disabled with FIPS built.

**Note:** In FIPS mode, OpenSSL only supports a small subset of elliptic curves.

### Dependencies on hardware

The pseudo random number generator (PRNG) provided by libica is disabled with FIPS mode. So only the DRBG can be used for the generation of random data. However, the DRBG needs at least MSA 2 to work. This means that FIPS mode cannot be used if no MSA 2 (introduced with z10) or higher is available.

## FIPS 140-3 mode dependencies

Read about the requirements posed on libica by the FIPS 140-3 compliance standards and how they are fulfilled.

- TDES/3DES functions are blocked when running in FIPS mode (FIPS 140-2 and later). See also "Use of TDES/3DES functions in FIPS mode" on page 103.
- Use a FIPS 140-3 compliant random number generator for ECC key generation. Therefore, libica transparently enforces ECC key generation via OpenSSL when running in FIPS mode. Triggering internal quality and integrity checks, OpenSSL ensures a FIPS-compliant ECC key generation. CPACF and CCA cryptographic coprocessors are not considered to be FIPS 140-3 compliant for ECC key generation. See also "Using ECC in FIPS mode" on page 47.
- The libica self-tests are enhanced to include self-tests for ECDSA via CPACF.
- ECC processing limits the available curves to the ones supported by CPACF with MSA9: p256, p384, p521. Self-tests for ECDH using CCA cryptographic coprocessors are also added for these three curves.
- Brainpool curves, Edwards (Ed25519/448), and Montgomery (X25519/448) curves are blocked, because they are not yet FIPS 140-3 approved as of December 2022.
- Provide key checking for the `ica_ecdh_derive_secret()` API function as required by *NIST Special Publication 800-56A, Revision 3*, sections 5.6.2.3.2 and 5.6.2.3.3. As libica does not know how the application created the key material, these checks inside the ECDH derive function are necessary.
- Only support FIPS approved RSA key lengths. libica version 4.1 allows RSA key lengths of 2048 bits and higher when running in FIPS mode. See also "Using RSA in FIPS mode" on page 44. Also, the minimum RSA public exponent size is 65537 when libica creates the value internally, that is, the application did not provide the public exponent.
- Use FIPS 140-3 compliant random number sources. The libica deterministic random bit generator (DRBG) is not FIPS 140-3 compliant and it is up to applications whether to use it or not. The DRBG API (see "NIST compliant ica_drbg functions" on page 36) is not blocked in FIPS mode.

## Enabling libica for FIPS mode

To use libica in FIPS mode, the library itself and also the Linux kernel need to be enabled. That is, the FIPS-enabled libica library can run in FIPS mode when the kernel FIPS flag is set.

### Enabling the Linux kernel for FIPS mode

A prerequisite for actually running the the FIPS-enabled libica in FIPS mode is to set the FIPS flag in the used Linux kernel configured for FIPS.

For all distributions, you need to enable the kernel FIPS mode at runtime by setting the kernel FIPS flag. To set this flag in `/proc/sys/crypto/fips_enabled`, boot or reboot with the kernel parameter `fips=1`.

For more information about setting and checking the kernel FIPS flag, refer to *Device Drivers, Features, and Commands*, SC33-8411. Or, for more distribution-specific information, refer to the publications provided by the specific distributor.

For systems with a Red Hat Enterprise Linux 8.3 distribution, you can use the **fips-mode-setup** command to enable FIPS:

```
fips-mode-setup --enable
```

## Enabling the libica library for FIPS mode

If you are using libica from a distribution, ensure that FIPS mode is supported, because a distribution may provide libica packages (RPM or DEB) both with or without FIPS support.

If you want to install libica from the source package, as described in "Installing libica from the source package" on page 5, then refer to the INSTALL file for information on how to install, configure, and build the libica library. You can then enable the FIPS mode at compile time by running the configure script with the **enable-fips** option:

```

# ./configure --enable-fips
# make
# make install
# make fipsinstall
```

# Chapter 3. Application programming interfaces

View a list of application programming interfaces (APIs) for the functions of the current version of libica. All functions are declared in `include/ica_api.h`.

**Note:** The list uses the following short-names for IBM processors:

**z16**
IBM z16

**z15™**
IBM z15 and IBM z15 Model T02

**z14**
IBM z14® and IBM z14 Model ZR1

**z13®**
IBM z13® and IBM z13s®

**zBC12**
IBM zEnterprise® BC12

**zEC12**
IBM zEnterprise EC12

**Note:** From a libica point of view, zEnterprise BC12 and zEnterprise EC12 are equivalent and zEnterprise EC12 is used in Table 1 on page 11 to denote the minimum required processor.

**z114**
IBM zEnterprise 114

- LinuxONE is supported whenever IBM z13 is supported.
- LinuxONE Emperor II and LinuxONE Rockhopper II are supported whenever IBM z14 is supported.
- LinuxONE III is supported whenever IBM z15 is supported.
- LinuxONE Emperor 4 is supported whenever IBM z16 is supported.

*Table 1. libica APIs*

| Function | libica API name | Key length in bits | Minimum required processor | Hardware support (CPACF or CEX*S) |
|---|---|---|---|---|
| **General support functions** | | | | |
| Open adapter handle | "ica_open_adapter" on page 20 | N/A | z114 | No |
| Close adapter handle | "ica_close_adapter" on page 21 | N/A | z114 | No |
| Enable/Disable SW fallbacks | "ica_set_fallback_mode" on page 21 | N/A | z114 | No |
| Enable/Disable offloading to crypto adapters | "ica_set_offload_mode" on page 22 | N/A | z114 | No |
| Enable/Disable counting of cryptographic operations | "ica_set_stats_mode" on page 22 | N/A | z114 | No |
| **Secure hash operations** | | | | |

*Table 1. libica APIs (continued)*

| Function | libica API name | Key length in bits | Minimum required processor | Hardware support (CPACF or CEX*S) |
|---|---|---|---|---|
| Secure hash using the SHA-1 algorithm (deprecated) | "ica_sha1" on page 130 | N/A | z114 | Yes |
| Secure hash using the SHA-224 algorithm | "ica_sha224" on page 23 | N/A | z114 | Yes |
| Secure hash using the SHA-256 algorithm | "ica_sha256" on page 24 | N/A | z114 | Yes |
| Secure hash using the SHA-384 algorithm | "ica_sha384" on page 25 | N/A | z114 | Yes |
| Secure hash using the SHA-512 algorithm | "ica_sha512" on page 26 | N/A | z114 | Yes |
| Secure hash using the SHA-512/224 algorithm | "ica_sha512_224" on page 27 | N/A | z114 | Yes |
| Secure hash using the SHA-512/256 algorithm | "ica_sha512_256" on page 28 | N/A | z114 | Yes |
| Secure hash using the SHA3-224 algorithm | "ica_sha3_224" on page 29 | N/A | z14 | Yes |
| Secure hash using the SHA3-256 algorithm | "ica_sha3_256" on page 30 | N/A | z14 | Yes |
| Secure hash using the SHA3-384 algorithm | "ica_sha3_384" on page 31 | N/A | z14 | Yes |
| Secure hash using the SHA3-512 algorithm | "ica_sha3_512" on page 32 | N/A | z14 | Yes |
| Secure hash using the SHAKE-128 algorithm | "ica_shake_128" on page 33 | N/A | z14 | Yes |
| Secure hash using the SHAKE-256 algorithm | "ica_shake_256" on page 34 | N/A | z14 | Yes |
| **Random number generation** | | | | |
| Generate a pseudo random number | "ica_random_number_generate" on page 37 | N/A | z114 | Yes |
| Generate pseudo random bits NIST compliant - instantiate | "ica_drbg_instantiate" on page 37 | N/A | z13 | Yes |
| Generate pseudo random bits NIST compliant - reseed | "ica_drbg_reseed" on page 38 | N/A | z13 | Yes |
| Generate pseudo random bits NIST compliant - generate | "ica_drbg_generate" on page 39 | N/A | z13 | Yes |

*Table 1. libica APIs (continued)*

| Function | libica API name | Key length in bits | Minimum required processor | Hardware support (CPACF or CEX*S) |
|---|---|---|---|---|
| Generate pseudo random bits NIST compliant - uninstantiate | "ica_drbg_uninstantiate" on page 40 | N/A | z13 | Yes |
| Generate pseudo random bits NIST compliant - health test | "ica_drbg_health_test" on page 40 | N/A | z13 | Yes |
| **Elliptic curve cryptography (ECC) functions** | | | | |
| Create an ICA_EC_KEY data structure for a new elliptic curve key | "ica_ec_key_new" on page 47 | N/A | z114 | Yes, for supported curves |
| Initialize an ICA_EC_KEY data structure with given values for private and public key | "ica_ec_key_init" on page 48 | N/A | z114 | Yes, for supported curves |
| Generate new ECC private and public key values | "ica_ec_key_generate" on page 49 | N/A | z114 | Yes, for supported curves |
| Free an ICA_EC_KEY data structure | "ica_ec_key_free" on page 49 | N/A | z114 | Yes, for supported curves |
| Calculate the Diffie-Hellman shared secret | "ica_ecdh_derive_secret" on page 50 | N/A | z114 | Yes, for supported curves |
| Obtain the public key of an ECC key pair | "ica_ec_get_public_key" on page 51 | N/A | z114 | Yes, for supported curves |
| Obtain the private key of an ECC key pair | "ica_ec_get_private_key" on page 51 | N/A | z114 | Yes, for supported curves |
| Create an ECDSA signature | "ica_ecdsa_sign" on page 52 | N/A | z114 | Yes, for supported curves |
| Create a deterministic ECDSA signature | "ica_ecdsa_sign_ex" on page 53 | N/A | z114 | Yes, for supported curves |
| Verify an ECDSA signature | "ica_ecdsa_verify" on page 54 | N/A | z114 | Yes, for supported curves |
| Allocate a new context for X25519 keys | "ica_x25519_ctx_new" on page 55 | N/A | z15 | Yes |

*Table 1. libica APIs (continued)*

| Function | libica API name | Key length in bits | Minimum required processor | Hardware support (CPACF or CEX*S) |
|---|---|---|---|---|
| Allocate a new context for X448 keys | "ica_x448_ctx_new" on page 56 | N/A | z15 | Yes |
| Allocate a new context for Ed25519 keys | "ica_ed25519_ctx_new" on page 56 | N/A | z15 | Yes |
| Allocate a new context for Ed448 keys | "ica_ed448_ctx_new" on page 57 | N/A | z15 | Yes |
| Copy the private and public X25519 key to the context | "ica_x25519_key_set" on page 57 | 256 | z15 | Yes |
| Copy the private and public X448 key to the context | "ica_x448_key_set" on page 58 | 448 | z15 | Yes |
| Copy the private and public Ed25519 key to the context | "ica_ed25519_key_set" on page 59 | 256 | z15 | Yes |
| Copy the private and public Ed448 key to the context | "ica_ed448_key_set" on page 59 | 448 | z15 | Yes |
| Copy the private and public X25519 key from the context | "ica_x25519_key_get" on page 60 | 256 | z15 | Yes |
| Copy the private and public X448 key from the context | "ica_x448_key_get" on page 61 | 448 | z15 | Yes |
| Copy the private and public Ed25519 key from the context | "ica_ed25519_key_get" on page 61 | 256 | z15 | Yes |
| Copy the private and public Ed448 key from the context | "ica_ed448_key_get" on page 62 | 448 | z15 | Yes |
| Generate an X25519 key | "ica_x25519_key_gen" on page 63 | 256 | z15 | Yes |
| Generate an X448 key | "ica_x448_key_gen" on page 63 | 448 | z15 | Yes |
| Generate an Ed25519 key | "ica_ed25519_key_gen" on page 64 | 256 | z15 | Yes |
| Generate an Ed448 key | "ica_ed448_key_gen" on page 64 | 448 | z15 | Yes |
| Derive a shared secret for X25519 keys | "ica_x25519_derive" on page 65 | 256 | z15 | Yes |
| Derive a shared secret for X448 keys | "ica_x448_derive" on page 65 | 448 | z15 | Yes |
| Sign an Ed25519 key | "ica_ed25519_sign" on page 66 | N/A | z15 | Yes |

*Table 1. libica APIs (continued)*

| Function | libica API name | Key length in bits | Minimum required processor | Hardware support (CPACF or CEX*S) |
|---|---|---|---|---|
| Sign an Ed448key | "ica_ed448_sign" on page 67 | N/A | z15 | Yes |
| Verify Ed25519 keys | "ica_ed25519_verify" on page 67 | N/A | z15 | Yes |
| Verify Ed448 keys | "ica_ed448_verify" on page 68 | N/A | z15 | Yes |
| Delete a context for an X25519 key | "ica_x25519_ctx_del" on page 69 | N/A | z15 | Yes |
| Delete a context for an X448 key | "ica_x448_ctx_del" on page 69 | N/A | z15 | Yes |
| Delete a context for an Ed25519 key | "ica_ed25519_ctx_del" on page 70 | N/A | z15 | Yes |
| Delete a context for an Ed448 key | "ica_ed448_ctx_del" on page 71 | N/A | z15 | Yes |
| **RSA key generation functions** | | | | |
| Generate RSA keys in modulus/exponent format | "ica_rsa_key_generate_mod_expo" on page 41 | N/A | z114 | No |
| Generate RSA keys in CRT format | "ica_rsa_key_generate_crt" on page 42 | N/A | z114 | No |
| **RSA encryption and decryption operations** | | | | |
| RSA encryption and decryption operation using a key in modulus/ exponent format | "ica_rsa_mod_expo" on page 44 | Depends on supp. key size of Crypto Express feature | z114 | No |
| RSA encryption and decryption operation using a key in Chinese-Remainder Theorem (CRT) format | "ica_rsa_crt" on page 45 | Depends on supp. key size of Crypto Express feature | z114 | CEX*S: Yes<br>CPACF: No |
| **AES functions** | | | | |
| AES with Cipher Block Chaining mode | "ica_aes_cbc" on page 72 | 128, 192, 256 | z114 | Yes |
| AES with CBC-Cipher text stealing mode | "ica_aes_cbc_cs" on page 73 | 128, 192, 256 | z114 | Yes |
| AES with Counter with Cipher Block Chaining - Message Authentication Code mode | "ica_aes_ccm" on page 74 | 128, 192, 256 | zEC12 | Yes |

*Table 1. libica APIs (continued)*

| Function | libica API name | Key length in bits | Minimum required processor | Hardware support (CPACF or CEX*S) |
|---|---|---|---|---|
| AES with Cipher Feedback mode | "ica_aes_cfb" on page 76 | 128, 192, 256 | z114 | Yes |
| AES with CMAC mode | "ica_aes_cmac" on page 77 | 128, 192, 256 | zEC12 | Yes |
| AES with CMAC mode process intermediate chunks | "ica_aes_cmac_intermediate" on page 78 | 128, 192, 256 | zEC12 | Yes |
| AES with CMAC mode process last chunk | "ica_aes_cmac_last" on page 79 | 128, 192, 256 | zEC12 | Yes |
| AES with Counter mode | "ica_aes_ctr" on page 80 | 128, 192, 256 | z114 | Yes |
| AES with Counter mode, using a list of counters | "ica_aes_ctrlist" on page 81 | 128, 192, 256 | z114 | Yes |
| AES with Electronic Code Book mode | "ica_aes_ecb" on page 82 | 128, 192, 256 | z114 | Yes |
| AES with Galois/ Counter Mode (GCM) for single operations | "ica_aes_gcm" on page 83 | 128, 192, 256 | z114 | Yes |
| AES with Galois/ Counter Mode (GCM) for streaming operations - initialize | "ica_aes_gcm_initialize" on page 85 | 128, 192, 256 | z114 | Yes |
| AES with Galois/ Counter Mode (GCM) for streaming operations - initialize with internally created IV | "ica_aes_gcm_initialize_fips" on page 86 | 128, 192, 256 | z114 | Yes |
| AES with Galois/ Counter Mode (GCM) for streaming operations - intermediate | "ica_aes_gcm_intermediate" on page 88 | 128, 192, 256 | z114 | Yes |
| AES with Galois/ Counter Mode (GCM) for streaming operations - last | "ica_aes_gcm_last" on page 90 | 128, 192, 256 | z114 | Yes |
| AES with Galois/ Counter Mode (GCM) for KMA exploitation - pointer to new GCM context | "ica_aes_gcm_kma_ctx_new" on page 91 | 128, 192, 256 | z114 | Yes |

*Table 1. libica APIs (continued)*

| Function | libica API name | Key length in bits | Minimum required processor | Hardware support (CPACF or CEX*S) |
|---|---|---|---|---|
| AES with Galois/ Counter Mode (GCM) for KMA exploitation - deallocate new GCM context | "ica_aes_gcm_kma_ctx_free" on page 92 | 128, 192, 256 | z114 | Yes |
| AES with Galois/ Counter Mode (GCM) for KMA exploitation - initialize new GCM context | "ica_aes_gcm_kma_init" on page 92 | 128, 192, 256 | z114 | Yes |
| AES with Galois/ Counter Mode (GCM) for KMA exploitation - initialize new GCM context in FIPS-mode | "ica_aes_gcm_kma_init_fips" on page 93 | 128, 192, 256 | z114 | Yes |
| AES with Galois/ Counter Mode (GCM) for KMA exploitation - perform encryption or decryption with authentication | "ica_aes_gcm_kma_update" on page 95 | 128, 192, 256 | z114 | Yes |
| AES with Galois/ Counter Mode (GCM) for KMA exploitation - get authentication tag | "ica_aes_gcm_kma_get_tag" on page 97 | 128, 192, 256 | z114 | Yes |
| AES with Galois/ Counter Mode (GCM) for KMA exploitation - verify authentication tag | "ica_aes_gcm_kma_verify_tag" on page 98 | 128, 192, 256 | z114 | Yes |
| AES with Output Feedback mode | "ica_aes_ofb" on page 98 | 128, 192, 256 | zEC12 | Yes |
| AES with XEX-based Tweaked Code Book mode (TCB) with CipherText Stealing (CTS) - single-part operation | "ica_aes_xts" on page 99 | 128, 256 | zEC12 | Yes |
| AES with XEX-based Tweaked Code Book mode (TCB) with CipherText Stealing (CTS) - multi-part operation | "ica_aes_xts_ex" on page 101 | 128, 256 | zEC12 | Yes |
| **TDES/3DES functions** | | | | |

*Table 1. libica APIs (continued)*

| **Function** | **libica API name** | **Key length in bits** | **Minimum required processor** | **Hardware support (CPACF or CEX*S)** |
|---|---|---|---|---|
| TDES with Cipher Block Chaining mode | "ica_3des_cbc" on page 103 | 168 | z114 | Yes |
| TDES with CBC-Cipher text Stealing mode | "ica_3des_cbc_cs" on page 104 | 168 | z114 | Yes |
| TDES with Cipher Feedback mode | "ica_3des_cfb" on page 105 | 168 | z114 | Yes |
| TDES with CMAC mode | "ica_3des_cmac" on page 106 | 168 | zEC12 | Yes |
| TDES with CMAC mode process intermediate chunks | "ica_3des_cmac_intermediate" on page 107 | 168 | zEC12 | Yes |
| TDES with CMAC mode process last chunk | "ica_3des_cmac_last" on page 108 | 168 | zEC12 | Yes |
| TDES with Counter mode | "ica_3des_ctr" on page 109 | 168 | z114 | Yes |
| TDES with Counter mode, using a list of counters | "ica_3des_ctrlist" on page 110 | 168 | z114 | Yes |
| TDES with Electronic Code Book mode | "ica_3des_ecb" on page 111 | 168 | z114 | Yes |
| TDES with Output Feedback mode | "ica_3des_ofb" on page 112 | 168 | zEC12 | Yes |
| **Information retrieval functions** | | | | |
| Return version information for libica | "ica_get_version" on page 113 | N/A | z114 | N/A |
| Return libica build information | "ica_get_build_version" on page 113 | N/A | z114 | N/A |
| Return hardware information about the used processor | "ica_get_hw_info" on page 114 | N/A | z114 | N/A |
| Return the processor's highest message security assist level (MSA Extension) | "ica_get_msa_level" on page 114 | N/A | z114 | N/A |
| Return a list of cryptographic mechanisms supported by libica | "ica_get_functionlist" on page 115 | N/A | z114 | N/A |
| **FIPS mode functions** | | | | |

*Table 1. libica APIs (continued)*

| Function | libica API name | Key length in bits | Minimum required processor | Hardware support (CPACF or CEX*S) |
|---|---|---|---|---|
| Queries and reruns a FIPS status and whether libica is running in FIPS mode | "ica_fips_status" on page 116 | N/A | z114 | N/A |
| Triggers the implemented self-tests when running in FIPS mode | "ica_fips_powerup_tests" on page 116 | N/A | z114 | N/A |
| Returns FIPS-compliance indication for each hardware function or any other mechanism | "ica_get_fips_indicator" on page 117 | N/A | z114 | N/A |
| **SIMD support** | | | | |
| Multiply two 512-bit numbers | "ica_mp_mul512" on page 118 | N/A | z14 | Yes |
| Square a 512-bit number | "ica_mp_sqr512" on page 118 | N/A | z14 | Yes |
| **DES functions (deprecated)** | | | | |
| DES with Cipher Block Chaining mode | "ica_des_cbc" on page 120 | 56 | z114 | Yes |
| DES with CBC-Cipher text stealing mode | "ica_des_cbc_cs" on page 121 | 56 | z114 | Yes |
| DES with Cipher Feedback mode | "ica_des_cfb" on page 122 | 56 | z114 | No |
| DES with CMAC mode | "ica_des_cmac" on page 123 | 56 | zEC12 | Yes |
| DES with CMAC mode process intermediate chunks | "ica_des_cmac_intermediate" on page 124 | 56 | zEC12 | Yes |
| DES with CMAC mode process last chunk | "ica_des_cmac_last" on page 125 | 56 | zEC12 | Yes |
| DES with Counter mode | "ica_des_ctr" on page 126 | 56 | z114 | Yes |
| DES with Counter mode, using a list of counters | "ica_des_ctrlist" on page 127 | 56 | z114 | Yes |
| DES with Electronic Code Book mode | "ica_des_ecb" on page 128 | 56 | z114 | Yes |
| DES with Output Feedback mode | "ica_des_ofb" on page 129 | 56 | zEC12 | Yes |

**Note:** If you are using the `libica-cex.so` module, but try to invoke a function that is not supported by the libica-cex library, then the function issues the following return code:

**EPERM**
Operation not permitted by hardware or software restrictions.

# General support functions

General support functions comprise the following APIs:

- Functions to open or close the crypto adapter. It is recommended to open the crypto adapter before using any of the libica crypto functions, and to close it after the last usage of the libica crypto functions. A valid adapter handle as input is explicitly required only for certain RSA-related and ECC-support functions.

  A pointer to the value DRIVER_NOT_LOADED indicates an invalid adapter handle. The parameter *ica_adapter_handle_t* is a redefine of int.
- If libica is built with software fallbacks enabled, a function is available to enable or disable software fallbacks using OpenSSL. With fallbacks enabled, libica attempts to perform requests by calling OpenSSL functions, if there is either no hardware support available or if the hardware returned an error.

  By default, the fallback mode is disabled for libica. In FIPS mode, OpenSSL only supports a small subset of elliptic curves.
- A function to enable or disable the offloading of cryptographic operations to cryptographic coprocessors. By default, offloading is disabled and libica processes cryptographic operations on CPACF instead of cryptographic coprocessors if functionality is available on both.

  You can also set the environment variable LIBICA_OFFLOAD_MODE to an integer not equal to zero to always prefer offloading to cryptographic coprocessors, if applicable.
- A function to enable or disable the counting of cryptographic operations. By default, libica counts its cryptographic operations in shared memory.

  You can also set the environment variable LIBICA_STATS_MODE to zero to disable the counting of cryptographic operations.

These functions are declared in: `include/ica_api.h`.

## ica_open_adapter

### Purpose

Opens an adapter.

### Format

```
unsigned int ica_open_adapter(ica_adapter_handle_t *adapter_handle);
```

### Parameters

**ica_adapter_handle_t *adapter_handle**
Pointer to the file descriptor for the adapter or to DRIVER_NOT_LOADED if opening the crypto adapter failed.

Opening an adapter succeeds if a cryptographic device is accessible for reading and writing. By default, cryptographic access must be available with the `/dev/z90crypt` path name for the adapter open request to succeed. If the environment variable LIBICA_CRYPT_DEVICE is set to a valid path name of an accessible cryptographic device, accessing the device with that path name takes precedence over the default path names.

### Return codes

**0**
Success

For return codes indicating exceptions, see “Return codes” on page 138.

## ica_close_adapter

### Purpose

Closes an adapter.

### Comments

This API closes a device handle.

### Format

```
unsigned int ica_close_adapter(ica_adapter_handle_t adapter_handle);
```

### Parameters

**ica_adapter_handle_t adapter_handle**
Pointer to a previously opened device handle.

### Return codes

**0**
Success

For return codes indicating exceptions, see “Return codes” on page 138.

## ica_set_fallback_mode

### Purpose

If libica is built with software fallbacks enabled, this function lets you disable or enable SW fallbacks. With the fallback mode enabled, libica attempts to cover a request by calling OpenSSL functions as fallback, when there is no hardware support available (for example, when the cryptographic coprocessors are offline). With SW fallbacks disabled, no attempts are made to fulfill the request, if there is no hardware support or available or if the hardware returned an error. Instead, the request issues return code ENODEV.

### Format

```
void ica_set_fallback_mode(int fallback_mode);
```

### Parameters

**int fallback_mode**

**1**
Enable software fallbacks. This is the default.

**0**
Disable software fallbacks.

### Return codes

None.

## ica_set_offload_mode

### Purpose

Lets you control whether to use CPACF or cryptographic coprocessors to perform cryptographic operations, if the required functionality is available on both. In such cases, libica processes cryptographic operations on CPACF by default. Enabling the offloading to cryptographic coprocessors might be reasonable in an environment where sufficient such coprocessors are available, and the CPU is to be used for other workloads.

You can also enable the offloading to cryptographic coprocessors using the environment variable LIBICA_OFFLOAD_MODE. If this environment variable is set to an integer not equal to zero, libica always uses cryptographic adapters, if applicable.

### Format

```
void ica_set_offload_mode(int offload_mode);
```

### Parameters

**int offload_mode**

**0**
Disable offloading cryptographic operations to cryptographic coprocessors. This is the default.

**any integer ≠ 0**
Enable offloading cryptographic operations to cryptographic coprocessors.

### Return codes

None.

## ica_set_stats_mode

### Purpose

Lets you disable or enable collecting statistics about the use of libica functions. By default, libica counts its cryptographic operations in shared memory.

You can also set the environment variable LIBICA_STATS_MODE to zero to disable the counting of cryptographic operations.

### Format

```
void ica_set_stats_mode(int stats_mode);
```

### Parameters

**int stats_mode**

**0**
Disable counting the use of libica functions.

**any integer ≠ 0**
Enable counting the use of libica functions. This is the default.

### Return codes

None.

# Secure hash operations

The provided hash functions perform secure hash on input data using the chosen algorithm of SHA-224, SHA-256, SHA-384, SHA-512, SHA-512-224, SHA-512-256, SHA3-224, SHA3-256, SHA3-384, SHA3-512, SHAKE-128, or SHAKE-256.

These functions are declared in: `include/ica_api.h`.

SHA context structures contain information about how much of the actual work was already performed. Also, it contains the part of the hash that is already produced. For the user, it is only interesting in cases where the message is not hashed at once, because the context is needed for further operations.

## ica_sha224

### Purpose

Performs a secure hash operation on the input data using the SHA-224 algorithm.

### Format

```
unsigned int ica_sha224(unsigned int message_part,
  unsigned int input_length,
  const unsigned char *input_data,
  sha256_context_t *sha256_context,
  unsigned char *output_data);
```

### Required hardware support

KIMD-SHA-256 and KLMD-SHA-256

### Parameters

**unsigned int message_part**

The message chaining state. This parameter must be one of the following values:

**SHA_MSG_PART_ONLY**

A single hash operation

**SHA_MSG_PART_FIRST**

The first part

**SHA_MSG_PART_MIDDLE**

The middle part

**SHA_MSG_PART_FINAL**

The last part

**unsigned int input_length**

Length in bytes of the input data to be hashed using the SHA-224 algorithm. For SHA_MSG_PART_FIRST and SHA_MSG_PART_MIDDLE calls, the byte length must be a multiple of 64, that is, the SHA-224 block size.

**const unsigned char *input_data**

Pointer to the input data to be hashed. This pointer must not be zero. So even in case of zero size message data, it must be set to a valid value.

**sha256_context_t *sha256_context**

Pointer to the SHA-256 context structure used to store intermediate values needed when chaining is used. The contents are ignored for message part SHA_MSG_PART_ONLY and SHA_MSG_PART_FIRST.

This structure must contain the returned value of the preceding call to `ica_sha224` for message part SHA_MSG_PART_MIDDLE and SHA_MSG_PART_FINAL. For message part SHA_MSG_PART_FIRST and SHA_MSG_PART_FINAL, the returned value can be used for a chained call of `ica_sha224`. Therefore, the application must not modify the contents of this structure in between chained calls.

**Note:** Due to the algorithm used by SHA-224, a SHA-256 context must be used.

**unsigned char *output_data**

Pointer to the buffer to contain the resulting hash data. The resulting output data has a length of `SHA224_HASH_LENGTH`. Make sure that the buffer is at least this size.

### Return codes

**0**

Success

For return codes indicating exceptions, see "Return codes" on page 138.

## ica_sha256

### Purpose

Performs a secure hash on the input data using the SHA-256 algorithm.

### Format

```
unsigned int ica_sha256(unsigned int message_part,
  unsigned int input_length,
  const unsigned char *input_data,
  sha256_context_t *sha256_context,
  unsigned char *output_data);
```

### Required hardware support

KIMD-SHA-256 and KLMD-SHA-256

### Parameters

**unsigned int message_part**

The message chaining state. This parameter must be one of the following values:

**SHA_MSG_PART_ONLY**

A single hash operation

**SHA_MSG_PART_FIRST**

The first part

**SHA_MSG_PART_MIDDLE**

The middle part

**SHA_MSG_PART_FINAL**

The last part

**unsigned int input_length**

Length in bytes of the input data to be hashed using the SHA-256 algorithm. For SHA_MSG_PART_FIRST and SHA_MSG_PART_MIDDLE calls, the byte length must be a multiple of 64, that is, the SHA-256 block size.

**const unsigned char *input_data**

Pointer to the input data to be hashed. This pointer must not be zero. So even in case of zero size message data, it must be set to a valid value.

**sha256_context_t *sha256_context**

Pointer to the SHA-256 context structure used to store intermediate values needed when chaining is used. The contents are ignored for message part SHA_MSG_PART_ONLY and SHA_MSG_PART_FIRST. This structure must contain the returned value of the preceding call to `ica_sha256` for message part SHA_MSG_PART_MIDDLE and SHA_MSG_PART_FINAL. For message part SHA_MSG_PART_FIRST and SHA_MSG_PART_FINAL, the returned value can be used for a chained call of `ica_sha256`. Therefore, the application must not modify the contents of this structure in between chained calls.

**unsigned char *output_data**

Pointer to the buffer to contain the resulting hash data. The resulting output data has a length of `SHA256_HASH_LENGTH`. Make sure that the buffer is at least this size.

### Return codes

**0**

Success

For return codes indicating exceptions, see "Return codes" on page 138.

## ica_sha384

### Purpose

Performs a secure hash on the input data using the SHA-384 algorithm.

### Format

```
unsigned int ica_sha384(unsigned int message_part,
  uint64_t input_length,
  const unsigned char *input_data,
  sha512_context_t *sha512_context,
  unsigned char *output_data);
```

### Required hardware support

KIMD-SHA-512 and KLMD-SHA-512

### Parameters

**unsigned int message_part**

The message chaining state. This parameter must be one of the following values:

**SHA_MSG_PART_ONLY**

A single hash operation

**SHA_MSG_PART_FIRST**

The first part

**SHA_MSG_PART_MIDDLE**

The middle part

**SHA_MSG_PART_FINAL**

The last part

**uint64_t input_length**

Length in bytes of the input data to be hashed using the SHA-384 algorithm. For SHA_MSG_PART_FIRST and SHA_MSG_PART_MIDDLE calls, the byte length must be a multiple of 128, that is, the SHA-384 block size.

**const unsigned char *input_data**

Pointer to the input data to be hashed. This pointer must not be zero. So even in case of zero size message data, it must be set to a valid value.

**sha512_context_t *sha512_context**

Pointer to the SHA-512 context structure used to store intermediate values needed when chaining is used. The contents are ignored for message part SHA_MSG_PART_ONLY and SHA_MSG_PART_FIRST. This structure must contain the returned value of the preceding call to `ica_sha384` for message part SHA_MSG_PART_MIDDLE and SHA_MSG_PART_FINAL. For message part SHA_MSG_PART_FIRST and SHA_MSG_PART_FINAL, the returned value can be used for a chained call of `ica_sha384`. Therefore, the application must not modify the contents of this structure in between chained calls.

**Note:** SHA-384 also uses a SHA-512 context

**unsigned char *output_data**

Pointer to the buffer to contain the resulting hash data. The resulting output data has a length of `SHA384_HASH_LENGTH`. Make sure that the buffer is at least this size.

## Return codes

**0**

Success

For return codes indicating exceptions, see "Return codes" on page 138.

# ica_sha512

## Purpose

Performs a secure hash operation on input data using the SHA-512 algorithm.

## Format

```
unsigned int ica_sha512(unsigned int message_part,
  uint64_t input_length,
  const unsigned char *input_data,
  sha512_context_t *sha512_context,
  unsigned char *output_data);
```

## Required hardware support

KIMD-SHA-512 and KLMD-SHA-512

## Parameters

**unsigned int message_part**

The message chaining state. This parameter must be one of the following values:

**SHA_MSG_PART_ONLY**

A single hash operation

**SHA_MSG_PART_FIRST**

The first part

**SHA_MSG_PART_MIDDLE**

The middle part

**SHA_MSG_PART_FINAL**

The last part

**uint64_t input_length**

Length in bytes of the input data to be hashed using the SHA-512 algorithm. For SHA_MSG_PART_FIRST and SHA_MSG_PART_MIDDLE calls, the byte length must be a multiple of 128, that is, the SHA-512 block size.

**const unsigned char *input_data**

Pointer to the input data to be hashed. This pointer must not be zero. So even in case of zero size message data, it must be set to a valid value.

**sha512_context_t *sha512_context**

Pointer to the SHA-512 context structure used to store intermediate values needed when chaining is used. The contents are ignored for message part SHA_MSG_PART_ONLY and SHA_MSG_PART_FIRST. This structure must contain the returned value of the preceding call to `ica_sha512` for message part SHA_MSG_PART_MIDDLE and SHA_MSG_PART_FINAL. For message part SHA_MSG_PART_FIRST and SHA_MSG_PART_FINAL, the returned value can be used for a chained call of `ica_sha512`. Therefore, the application must not modify the contents of this structure in between chained calls.

**unsigned char *output_data**

Pointer to the buffer to contain the resulting hash data. The resulting output data has a length of `SHA512_HASH_LENGTH`. Make sure that the buffer is at least this size.

### Return codes

**0**

Success

For return codes indicating exceptions, see "Return codes" on page 138.

## ica_sha512_224

### Purpose

Performs a secure hash operation on input data using the SHA-512/224 algorithm.

### Format

```
unsigned int ica_sha512_224(unsigned int message_part,
  uint64_t input_length,
  const unsigned char *input_data,
  sha512_context_t *sha512_context,
  unsigned char *output_data);
```

### Required hardware support

KIMD-SHA-512 or KLMD-SHA-512

### Parameters

**unsigned int message_part**

The message chaining state. This parameter must be one of the following values:

**SHA_MSG_PART_ONLY**

A single hash operation

**SHA_MSG_PART_FIRST**

The first part

**SHA_MSG_PART_MIDDLE**

The middle part

**SHA_MSG_PART_FINAL**

The last part

**uint64_t input_length**

Length in bytes of the input data to be hashed using the SHA-512/224 algorithm. This value must be greater than zero. For SHA_MSG_PART_FIRST and SHA_MSG_PART_MIDDLE calls, the byte length must be a multiple of 128, that is, the SHA-512 block size.

**const unsigned char *input_data**

Pointer to the input data to be hashed. This pointer must not be zero.

**sha512_context_t *sha512_context**

Pointer to the SHA-512 context structure used to store intermediate values needed when chaining is used. The content is ignored for message part SHA_MSG_PART_ONLY and SHA_MSG_PART_FIRST. This structure must contain the returned value of the preceding call to `ica_sha512_256` for message part SHA_MSG_PART_MIDDLE and SHA_MSG_PART_FINAL. For message part SHA_MSG_PART_FIRST and SHA_MSG_PART_FINAL, the returned value can be used for a chained call of `ica_sha512_256`. Therefore, the application must not modify the contents of this structure between chained calls.

**unsigned char *output_data**

Pointer to the buffer to contain the resulting hash data. The resulting output data has a length of `SHA512_256_HASH_LENGTH`. Make sure that the buffer is at least this size.

### Return codes

**0**

Success

For return codes indicating exceptions, see "Return codes" on page 138.

## ica_sha512_256

### Purpose

Performs a secure hash operation on input data using the SHA-512/256 algorithm.

### Format

```
unsigned int ica_sha512_256(unsigned int message_part,
  uint64_t input_length,
  const unsigned char *input_data,
  sha512_context_t *sha512_context,
  unsigned char *output_data);
```

### Required hardware support

KIMD-SHA-512 or KLMD-SHA-512

### Parameters

**unsigned int message_part**

The message chaining state. This parameter must be one of the following values:

**SHA_MSG_PART_ONLY**

A single hash operation

**SHA_MSG_PART_FIRST**

The first part

**SHA_MSG_PART_MIDDLE**

The middle part

**SHA_MSG_PART_FINAL**

The last part

**uint64_t input_length**

Length in bytes of the input data to be hashed using the SHA-512/256 algorithm. This value must be greater than zero. For SHA_MSG_PART_FIRST and SHA_MSG_PART_MIDDLE calls, the byte length must be a multiple of 128, that is, the SHA-512 block size.

**const unsigned char *input_data**

Pointer to the input data to be hashed. This pointer must not be zero.

**sha512_context_t *sha512_context**

Pointer to the SHA-512 context structure used to store intermediate values needed when chaining is used. The content is ignored for message part SHA_MSG_PART_ONLY and SHA_MSG_PART_FIRST. This structure must contain the returned value of the preceding call to `ica_sha512` for message part SHA_MSG_PART_MIDDLE and SHA_MSG_PART_FINAL. For message part SHA_MSG_PART_FIRST and SHA_MSG_PART_FINAL, the returned value can be used for a chained call of `ica_sha512`. Therefore, the application must not modify the contents of this structure in between chained calls.

**unsigned char *output_data**

Pointer to the buffer to contain the resulting hash data. The resulting output data has a length of `SHA512_HASH_LENGTH`. Make sure that the buffer is at least this size.

### Return codes

**0**

Success

For return codes indicating exceptions, see "Return codes" on page 138.

## ica_sha3_224

### Purpose

Performs a secure hash operation on input data using the SHA3-224 algorithm.

### Format

```
unsigned int ica_sha3_224(unsigned int message_part,
  unsigned int input_length,
  const unsigned char *input_data,
  sha3_224_context_t *sha3_224_context,
  unsigned char *output_data);
```

### Required hardware support

KIMD-SHA3-224 and KLMD-SHA3-224

### Parameters

**unsigned int message_part**

The message chaining state. This parameter must be one of the following values:

**SHA_MSG_PART_ONLY**

a single hash operation.

**SHA_MSG_PART_FIRST**

the first part.

**SHA_MSG_PART_MIDDLE**

the middle part.

**SHA_MSG_PART_FINAL**

the last part.

**unsigned int input_length**

Length in bytes of the input data to be hashed using the SHA3-224 algorithm. For SHA_MSG_PART_FIRST and SHA_MSG_PART_MIDDLE calls, the byte length must be a multiple of 144, that is, the SHA3-224 block size.

**const unsigned char *input_data**

Pointer to the input data to be hashed. This pointer must not be NULL. So even in case of zero size message data, it must be set to a valid value.

**sha3_224_context_t *sha3_224_context**

Pointer to the SHA3-224 context structure used to store intermediate values needed when chaining is used. The contents are ignored for message part SHA_MSG_PART_ONLY and SHA_MSG_PART_FIRST. This structure must contain the returned value of the preceding call to `ica_sha3_224` for message part SHA_MSG_PART_MIDDLE and SHA_MSG_PART_FINAL. For message part SHA_MSG_PART_FIRST and SHA_MSG_PART_MIDDLE, the returned value can be used for a chained call of `ica_sha3_224`. Therefore, the application must not modify the contents of this structure in between chained calls.

**unsigned char *output_data**

Pointer to the buffer to contain the resulting hash data. This pointer must always be available and must not be NULL. The resulting output data has a length of `SHA3_224_HASH_LENGTH`. Make sure that the buffer is at least this size.

### Return codes

**0**

Success

For return codes indicating exceptions, see "Return codes" on page 138.

## ica_sha3_256

### Purpose

Performs a secure hash operation on input data using the SHA3-256 algorithm.

### Format

```
unsigned int ica_sha3_256(unsigned int message_part,
  unsigned int input_length,
  const unsigned char *input_data,
  sha3_256_context_t *sha3_256_context,
  unsigned char *output_data);
```

### Required hardware support

KIMD-SHA3-256 and KLMD-SHA3-256

### Parameters

**unsigned int message_part**

The message chaining state. This parameter must be one of the following values:

**SHA_MSG_PART_ONLY**

a single hash operation.

**SHA_MSG_PART_FIRST**

the first part.

**SHA_MSG_PART_MIDDLE**

the middle part.

**SHA_MSG_PART_FINAL**

the last part.

**unsigned int input_length**

Length in bytes of the input data to be hashed using the SHA3-256 algorithm. For SHA_MSG_PART_FIRST and SHA_MSG_PART_MIDDLE calls, the byte length must be a multiple of 136, that is, the SHA3-256 block size.

**const unsigned char *input_data**

Pointer to the input data to be hashed. This pointer must not be zero. So even in case of zero size message data, it must be set to a valid value.

**sha3_256_context_t *sha3_256_context**

Pointer to the SHA3-256 context structure used to store intermediate values needed when chaining is used. The contents are ignored for message part SHA_MSG_PART_ONLY and SHA_MSG_PART_FIRST. This structure must contain the returned value of the preceding call to `ica_sha3_256` for message part SHA_MSG_PART_MIDDLE and SHA_MSG_PART_FINAL. For message part SHA_MSG_PART_FIRST and SHA_MSG_PART_MIDDLE, the returned value can be used for a chained call of `ica_sha3_256`. Therefore, the application must not modify the contents of this structure in between chained calls.

**unsigned char *output_data**

Pointer to the buffer to contain the resulting hash data. This pointer must always be available and must not be NULL. The resulting output data has a length of SHA3_256_HASH_LENGTH. Make sure that the buffer is at least this size.

### Return codes

**0**

Success

For return codes indicating exceptions, see “Return codes” on page 138.

## ica_sha3_384

### Purpose

Performs a secure hash operation on input data using the SHA3-384 algorithm.

### Format

```
unsigned int ica_sha3_384(unsigned int message_part,
  uint64_t input_length,
  const unsigned char *input_data,
  sha3_384_context_t *sha3_384_context,
  unsigned char *output_data);
```

### Required hardware support

KIMD-SHA3-384 and KLMD-SHA3-384

### Parameters

**unsigned int message_part**

The message chaining state. This parameter must be one of the following values:

**SHA_MSG_PART_ONLY**

a single hash operation.

**SHA_MSG_PART_FIRST**

the first part.

**SHA_MSG_PART_MIDDLE**

the middle part.

**SHA_MSG_PART_FINAL**
the last part.

**uint64_t input_length**
Length in bytes of the input data to be hashed using the SHA3-384 algorithm. For SHA_MSG_PART_FIRST and SHA_MSG_PART_MIDDLE calls, the byte length must be a multiple of 104, that is, the SHA3-384 block size.

**const unsigned char *input_data**
Pointer to the input data to be hashed. This pointer must not be zero. So even in case of zero size message data, it must be set to a valid value.

**sha3_384_context_t *sha3_384_context**
Pointer to the SHA3-384 context structure used to store intermediate values needed when chaining is used. The contents are ignored for message part SHA_MSG_PART_ONLY and SHA_MSG_PART_FIRST. This structure must contain the returned value of the preceding call to `ica_sha3_384` for message part SHA_MSG_PART_MIDDLE and SHA_MSG_PART_FINAL. For message part SHA_MSG_PART_FIRST and SHA_MSG_PART_MIDDLE, the returned value can be used for a chained call of `ica_sha3_384`. Therefore, the application must not modify the contents of this structure in between chained calls.

**unsigned char *output_data**
Pointer to the buffer to contain the resulting hash data. This pointer must be available and must not be NULL. The resulting output data has a length of SHA3_384_HASH_LENGTH. Make sure that the buffer is at least this size.

### Return codes

**0**
Success

For return codes indicating exceptions, see "Return codes" on page 138.

## ica_sha3_512

### Purpose

Performs a secure hash operation on input data using the SHA3-512 algorithm.

### Format

```
unsigned int ica_sha3_512(unsigned int message_part,
  uint64_t input_length,
  const unsigned char *input_data,
  sha3_512_context_t *sha3_512_context,
  unsigned char *output_data);
```

### Required hardware support

KIMD-SHA3-512 and KLMD-SHA3-512

### Parameters

**unsigned int message_part**
The message chaining state. This parameter must be one of the following values:

**SHA_MSG_PART_ONLY**
a single hash operation.

**SHA_MSG_PART_FIRST**
the first part.

**SHA_MSG_PART_MIDDLE**

the middle part.

**SHA_MSG_PART_FINAL**

the last part.

**uint64_t input_length**

Length in bytes of the input data to be hashed using the SHA3-512 algorithm. For SHA_MSG_PART_FIRST and SHA_MSG_PART_MIDDLE calls, the byte length must be a multiple of 64, that is, the SHA3-512 block size.

**const unsigned char *input_data**

Pointer to the input data to be hashed. This pointer must not be zero. So even in case of zero size message data, it must be set to a valid value.

**sha3_512_context_t *sha3_512_context**

Pointer to the SHA3-512 context structure used to store intermediate values needed when chaining is used. The contents are ignored for message part SHA_MSG_PART_ONLY and SHA_MSG_PART_FIRST. This structure must contain the returned value of the preceding call to `ica_sha3_512` for message part SHA_MSG_PART_MIDDLE and SHA_MSG_PART_FINAL. For message part SHA_MSG_PART_FIRST and SHA_MSG_PART_MIDDLE, the returned value can be used for a chained call of `ica_sha3_512`. Therefore, the application must not modify the contents of this structure in between chained calls.

**unsigned char *output_data**

Pointer to the buffer to contain the resulting hash data. This pointer must be available and must not be NULL. The resulting output data has a length of `SHA3_512_HASH_LENGTH`. Make sure that the buffer is at least this size.

### Return codes

**0**

Success

For return codes indicating exceptions, see "Return codes" on page 138.

## ica_shake_128

### Purpose

Performs a secure hash operation on the input data using the SHAKE-128 algorithm. Unlike other hash functions, the SHAKE algorithm has no fixed output length. This means that you can choose any output length which is a multiple of 8 bits (1 byte).

### Format

```
unsigned int ica_shake_128(unsigned int message_part,
  uint64_t input_length,
  const unsigned char *input_data,
  shake_128_context_t *shake_128_context,
  unsigned char *output_data, unsigned int output_length);
```

### Required hardware support

KIMD-SHAKE-128 and KLMD-SHAKE-128

### Parameters

**unsigned int message_part**

The message chaining state. This parameter must be one of the following values:

**SHA_MSG_PART_ONLY**
a single hash operation.

**SHA_MSG_PART_FIRST**
the first part.

**SHA_MSG_PART_MIDDLE**
the middle part.

**SHA_MSG_PART_FINAL**
the last part.

**uint64_t input_length**
Length in bytes of the input data to be hashed using the SHAKE-128 algorithm. For SHA_MSG_PART_FIRST and SHA_MSG_PART_MIDDLE calls, the byte length must be a multiple of 168, that is, the SHAKE-128 block size.

**const unsigned char *input_data**
Pointer to the input data to be hashed. This pointer must not be zero. So even in case of zero size message data, it must be set to a valid value.

**shake_128_context_t *shake_128_context**
Pointer to the SHAKE-128 context structure used to store intermediate values needed when chaining is used. The contents are ignored for message part SHA_MSG_PART_ONLY and SHA_MSG_PART_FIRST. This structure must contain the returned value of the preceding call to `ica_shake_128` for message part SHA_MSG_PART_MIDDLE and SHA_MSG_PART_FINAL. For message part SHA_MSG_PART_FIRST and SHA_MSG_PART_MIDDLE, the returned value can be used for a chained call of `ica_shake_128`. Therefore, the application must not modify the contents of this structure in between chained calls.

**unsigned char *output_data**
Pointer to the buffer to contain the resulting hash data. Done. This pointer must be available and must not be NULL. The resulting output data has a length as specified in parameter **`output_length`**. Make sure that the buffer is at least this size.

**unsigned int output_length**
The resulting length of the hashed data. The output length must not be zero and must be 1 byte or more for all message parts.

### Return codes

**0**
Success

For return codes indicating exceptions, see "Return codes" on page 138.

## ica_shake_256

### Purpose

Performs a secure hash operation on the input data using the SHAKE-256 algorithm. Unlike other hash functions, the SHAKE algorithm has no fixed output length. This means that you can choose any output length which is a multiple of 8 bits (1 byte).

### Format

```
unsigned int ica_shake_256(unsigned int message_part,
  uint64_t input_length,
  const unsigned char *input_data,
  shake_256_context_t *shake_256_context,
  unsigned char *output_data, unsigned int output_length);
```

### Required hardware support

KIMD-SHAKE-256 and KLMD-SHAKE-256

### Parameters

**unsigned int message_part**
The message chaining state. This parameter must be one of the following values:

**SHA_MSG_PART_ONLY**
a single hash operation.

**SHA_MSG_PART_FIRST**
the first part.

**SHA_MSG_PART_MIDDLE**
the middle part.

**SHA_MSG_PART_FINAL**
the last part.

**uint64_t input_length**
Length in bytes of the input data to be hashed using the SHAKE-256 algorithm. For SHA_MSG_PART_FIRST and SHA_MSG_PART_MIDDLE calls, the byte length must be a multiple of 136, that is, the SHAKE-256 block size.

**const unsigned char *input_data**
Pointer to the input data to be hashed. This pointer must not be zero. So even in case of zero size message data, it must be set to a valid value.

**shake_256_context_t *shake_256_context**
Pointer to the SHAKE-256 context structure used to store intermediate values needed when chaining is used. The contents are ignored for message part SHA_MSG_PART_ONLY and SHA_MSG_PART_FIRST. This structure must contain the returned value of the preceding call to `ica_shake_256` for message part SHA_MSG_PART_MIDDLE and SHA_MSG_PART_FINAL. For message part SHA_MSG_PART_FIRST and SHA_MSG_PART_MIDDLE, the returned value can be used for a chained call of `ica_shake_256`. Therefore, the application must not modify the contents of this structure in between chained calls.

**unsigned char *output_data**
Pointer to the buffer to contain the resulting hash data. This pointer must be available and must not be NULL. The resulting output data has a length as returned in parameter **`output_length`**. Make sure that the buffer is at least this size.

**unsigned int output_length**
The resulting length of the hashed data. The output length must not be zero and must be 1 byte or more for all message parts.

### Return codes

**0**
Success

For return codes indicating exceptions, see "Return codes" on page 138.

## Pseudo random number generation functions

libica provides two methods of random number (random bit) generation.

The two provided random number or random bit generators are:

- a conventional random number generator ("ica_random_number_generate" on page 37).
- a NIST SP800-90A compliant deterministic random bit generator (DRBG). This generator is implemented by a combination of five separate functional APIs and is hereafter referred to as

**ica_drbg** (see “NIST compliant ica_drbg functions” on page 36) to denote the complete generator as a whole.

**Note:** The **ica_drbg** API does not use a random source that is compliant to FIPS 140-3. However, this API is not blocked if libica is running in FIPS mode. Therefore applications that are obliged to only use FIPS 140-3 compliant APIs, must not use **ica_drbg** functions.

These functions are declared in: `include/ica_api.h`.

## Conventional `ica_random_number_generate` function

libica initialization tries to seed the CPACF random generator. To get the seed, device `/dev/hwrng` is opened. Device `/dev/hwrng` provides true random data from crypto adapters over the crypto device driver (main module name is **ap**, with an alias name **z90crypt**, which is linking to **ap**). If that fails, the initialization mechanism uses device `/dev/urandom`. Within the initialization, a byte counter *s390_byte_count* is set to 0. If the CPACF pseudo random generator is available, after 4096 bytes of the pseudo random number are generated, the random number generator is seeded again. If the CPACF pseudo random generator is not available, random numbers are read from `/dev/urandom`.

Since libica version 2.6, this API internally invokes the NIST compliant **ica_drbg** functionality. The original code of this API is only processed if no MSA5, or at least no MSA2 support is available, which is the prerequisite of the **ica_drbg** API (see “NIST compliant ica_drbg functions” on page 36).

## NIST compliant `ica_drbg` functions

The following APIs make up the complete **ica_drbg** functionality:

- “ica_drbg_instantiate” on page 37
- “ica_drbg_reseed” on page 38
- “ica_drbg_generate” on page 39
- “ica_drbg_uninstantiate” on page 40
- “ica_drbg_health_test” on page 40

The implementation is designed to be thread-safe such that different threads can share the same **ica_drbg** instantiation.

The **ica_drbg** functionality uses certain definitions and supports the following DRBG mechanisms as shown in Table 2 on page 36.

```
typedef struct ica_drbg_mech ica_drbg_mech_t;
extern ica_drbg_mech_t *const ICA_DRBG_SHA512;
```

*Table 2. Supported DRBG mechanisms*

| DRBG mechanism | supported security strengths (in bits) | max. byte length of pers/add parameters |
|---|---|---|
| DRBG_SHA512 | 112, 128, 196, 256 | 256 / 256 |

The following information list satisfies the NIST SP800-90A documentation requirements:

- Entropy input is read from `/dev/hwrng`. If `/dev/hwrng` is not available, the entropy input is read from `/dev/prandom`.
- **ica_drbg** provides the **ica_drbg_health_test** interface for validation and health testing. This function together with test parameters can be found in `libica/src/include/s390_drbg.h`. Nonce and entropy input can be injected via these parameters for the purpose of known answer testing.
- No further support functions other than health testing are supported.
- The only DRBG mechanism currently implemented is Hash_DRBG using SHA-512.
- **ica_drbg** supports 112, 128, 196, and 256 bits of security.

- **`ica_drbg`** supports prediction resistance.
- The generate function is tested every $2^{64}$ - 1 calls. This interval size is chosen, because CPACF hardware failures should not happen frequently.
- The integrity of the health test can be determined by inspecting the `checksum/hash` of the package before install.

## ica_random_number_generate

### Purpose

This function generates a pseudo random number. Parameter **ouput_data* is a pointer to a buffer of byte length *output_length*. *output_length* number of bytes of pseudo random data is placed in the buffer pointed to by *output_data*.

### Format

```
unsigned int ica_random_number_generate(unsigned int output_length,
  unsigned char *output_data);
```

### Required hardware support

KMC-PRNG

### Parameters

**unsigned int output_length**

Length in bytes of the *output_data* buffer, and the length of the generated pseudo random number.

**unsigned char *output_data**

Pointer to the buffer to receive the generated pseudo random number.

### Return codes

**0**

Success

For return codes indicating exceptions, see "Return codes" on page 138.

## ica_drbg_instantiate

### Purpose

This function instantiates a NIST SP800-90A compliant deterministic random bit generator.

### Format

```
int ica_drbg_instantiate(ica_drbg_t **sh,
  int sec,
  bool pr,
  ica_drbg_mech_t *mech,
  const unsigned char *pers,
  size_t pers_len);
```

### Parameters

**ica_drbg_t **sh**

State handle pointer. The (invalid) state handle is set to identify the new DRBG instantiation and thus becomes valid.

**int sec**

Requested security strength in bits of the new DRBG instantiation. The security strength is set to the lowest value supported by its DRBG mechanism that is greater than or equal to your selected **sec** value (see Table 2 on page 36). For example, if you request security strength 160 for your instance, it is actually set to 196.

**bool pr**

Prediction resistance flag. Indicates whether or not prediction resistance may be required by the consuming application during one or more requests for pseudo random bytes.

**ica_drbg_mech_t *mech**

Pointer to the mechanism type selected for the new DRBG instantiation. The new instantiation is then of this mechanism type. For available mechanisms, see Table 2 on page 36.

**const unsigned char *pers**

Pointer to a personalization string. This is optional input that provides personalization information. The personalization string should be unique for all instantiations of the same mechanism type. NULL indicates that no personalization string is used (not recommended).

**size_t pers_len**

Length in bytes of the string referenced by ***pers**.

### Return codes

**0**

Success

**ENOTSUP**

Prediction resistance or the requested security strength is not supported.

**EPERM**

Failed to obtain a valid timestamp from clock.

**ICA_DBRG_HEALTH_TEST_FAIL**

Health test failed, see "ica_drbg_health_test" on page 40.

**ICA_DBRG_ENTROPY_SOURCE_FAIL**

Entropy source failed.

## ica_drbg_reseed

### Purpose

This function reseeds a NIST SP800-90A compliant DRBG instantiation from **ica_drbg_instantiate**.

### Format

```
int ica_drbg_reseed(ica_drbg_t *sh,
  bool pr,
  const unsigned char *add,
  size_t add_len);
```

### Parameters

**ica_drbg_t *sh**

State handle pointer. Identifies the DRBG instantiation to be reseeded.

**bool pr**
: Prediction resistance request. Indicates whether or not prediction resistance is required.

**const unsigned char *add**
: Pointer to additional optional input. NULL indicates that no additional input is used.

**size_t add_len**
: Length in bytes of parameter **add**.

### Return codes

**0**
: Success

**ENOTSUP**
: Prediction resistance is not supported.

**ICA_DBRG_HEALTH_TEST_FAIL**
: Health test failed, see "ica_drbg_health_test" on page 40.

**ICA_DBRG_ENTROPY_SOURCE_FAIL**
: Entropy source failed.

## ica_drbg_generate

### Purpose

This function requests pseud random bytes from an **ica_drbg** instantiation created by the **ica_drbg_instantiate** function.

### Format

```
int ica_drbg_generate(ica_drbg_t *sh,
  int sec,
  bool pr,
  const unsigned char *add,
  size_t add_len,
  unsigned char *prnd,
  size_t prnd_len);
```

### Parameters

**ica_drbg_t *sh**
: State handle pointer. Identifies the DRBG instantiation from which pseudorandom bytes are requested.

**int sec**
: Requested security strength: Minimum bits of security that the generated pseudo random bytes shall offer.

**bool pr**
: Prediction resistance request. Indicates whether or not prediction resistance is required.

**const unsigned char *add**
: Pointer to additional optional input. NULL indicates that no additional input is used.

**size_t add_len**
: Length in bytes of parameter **add**.

**unsigned char *prnd**
: Pointer to the generated pseudo random bytes.

**size_t prnd_len**
: Length in bytes of parameter **prnd**, which corresponds to the number of generated pseudo random bytes.

### Return codes

**0**
Success

**ENOTSUP**
Prediction resistance or the requested security strength is not supported.

**EPERM**
Reseed required.

**ICA_DBRG_HEALTH_TEST_FAIL**
Health test failed, see "ica_drbg_health_test" on page 40.

**ICA_DBRG_ENTROPY_SOURCE_FAIL**
Entropy source failed.

For return codes indicating exceptions, see "Return codes" on page 138.

## ica_drbg_uninstantiate

### Purpose

This function destroys an existing **ica_drbg** instance.

### Format

```
int ica_drbg_uninstantiate(ica_drbg_t **sh);
```

### Parameters

**ica_drbg_t **sh**
State handle pointer. The corresponding DRBG instantiation is destroyed and the state handle is set to NULL (invalid).

### Return codes

**0**
Success

For return codes indicating exceptions, see "Return codes" on page 138.

## ica_drbg_health_test

### Purpose

This function runs a health test for the complete **ica_drbg** function mechanism.

### Format

```
int ica_drbg_health_test(void *func,
  int sec,
  bool pr,
  ica_drbg_mech_t *mech);
```

### Parameters

**void *func**
Pointer indicating which function should be tested. Options are:

ica_drbg_instantiate
ica_drbg_reseed
ica_drbg_generate

The `ica_drbg_instantiate` function is tested whenever other functions are tested.

**int sec**
Security strength. Argument for the call to the function denoted by parameter **`func`**.

**bool pr**
Prediction resistance. Argument for the call to the function denoted by parameter **`func`**.

**ica_drbg_mech_t *mech**
Pointer to the mechanism to be tested.

### Return codes

**0**
Success

**ICA_DBRG_HEALTH_TEST_FAIL**
Health test failed.

**ENOTSUP**
Prediction resistance or the requested security strength is not supported.

**ICA_DBRG_ENTROPY_SOURCE_FAIL**
Entropy source failed.

For return codes indicating exceptions, see "Return codes" on page 138.

# RSA key generation functions

These functions generate an RSA public/private key pair. They are performed using software through OpenSSL. Hardware is not used.

These functions are declared in: `include/ica_api.h`.

**Note:** In FIPS mode, RSA key lengths are limited to 2048 bits and higher, and the public exponent must be at least 65537.

## ica_rsa_key_generate_mod_expo

### Purpose

Generates RSA keys in modulus/exponent format.

### Comments

This function allows users to generate RSA keys for any granularity in the range 57 - 4096 bits. For specific information about some of these parameters, see the considerations in "Data structures" on page 134.

### Format

```
unsigned int ica_rsa_key_generate_mod_expo(ica_adapter_handle_t adapter_handle,
  unsigned int modulus_bit_length,
  ica_rsa_key_mod_expo_t *public_key,
  ica_rsa_key_mod_expo_t *private_key);
```

### Parameters

**ica_adapter_handle_t adapter_handle**
Pointer to a previously opened device handle.

**unsigned int modulus_bit_length**
Length in bits of the modulus. This value should comply with the length of the keys (in bytes), according to this calculation:

```
key_length = (modulus_bits + 7) / 8
```

**ica_rsa_key_mod_expo_t *public_key**
Pointer to where the generated public key is to be placed. If the *exponent* element in the public key is not set, it is randomly generated. A poorly chosen *exponent* could result in the program looping endlessly. Common public exponents are 3 and 65537.

**ica_rsa_key_mod_expo_t *private_key**
Pointer to where the generated private key in modulus/exponent format is to be placed. The length of both the private and public keys should be set in bytes. This value should comply with the length of the keys (in bytes), according to this calculation:

```
key_length = (modulus_bits + 7) / 8
```

### Return codes

**0**
Success

**EPERM**

Used RSA key is > 4K.

For return codes indicating exceptions, see “Return codes” on page 138.

## ica_rsa_key_generate_crt

### Purpose

Generates RSA keys in Chinese-Remainder Theorem (CRT) format.

### Comments

This function allows users to generate RSA keys for any granularity in the range 57 - 4096 bits. For specific information about some of these parameters, see the considerations in “Data structures” on page 134.

### Format

```
unsigned int ica_rsa_key_generate_crt(ica_adapter_handle_t adapter_handle,
  unsigned int modulus_bit_length,
  ica_rsa_key_mod_expo_t *public_key,
  ica_rsa_key_crt_t *private_key);
```

### Parameters

**ica_adapter_handle_t adapter_handle**
Pointer to a previously opened device handle.

**unsigned int modulus_bit_length**
Length in bits of the modulus part of the key. This value should comply with the length of the keys (in bytes), according to this calculation:

```
key_length = (modulus_bits + 7) / 8
```

**ica_rsa_key_mod_expo_t *public_key**
Pointer to where the generated public key is to be placed. If the *exponent* element in the public key is not set, it is randomly generated. A poorly chosen *exponent* can result in the program looping endlessly. Common public exponents are 3 and 65537.

**ica_rsa_key_crt_t *private_key**
Pointer to where the generated private key in CRT format is to be placed. Length of both private and public keys should be set in bytes. This value should comply with the length of the keys (in bytes), according to this calculation

```
key_length = (modulus_bits + 7) / 8
```

### Return codes

**0**
Success

**EPERM**

Used RSA key is > 4K.

For return codes indicating exceptions, see “Return codes” on page 138.

## ica_rsa_crt_key_check

### Purpose

Analyzes an RSA CRT key and checks if the components are conform with the IBM cryptographic architecture. If necessary the key is converted to a conform format that can be used for IBM cryptographic hardware acceleration.

Checks if the RSA key credentials in CRT format are presented in privileged form, respectively whether prime **p** is greater than prime **q** (p > q) In case of p < q, key credentials **p** and **q** as well as **dp** and **dq** are swapped and qInverse is recalculated.

### Format

```
unsigned int ica_rsa_crt_key_check(ica_rsa_key_crt_t *rsa_key);
```

### Parameters

**ica_rsa_key_crt_t *rsa_key**
Pointer to the key to be used in CRT format.

### Return codes

**0**
All key credentials are in the correct format.

**1**
Key credentials were recalculated.

**ENOMEM**
Memory allocation fails.

**EPERM**

Used RSA key is > 4K.

For return codes indicating exceptions, see “Return codes” on page 138.

# RSA encrypt and decrypt operations

These functions perform a modulus/exponent operation using an RSA key whose type is either *ica_rsa_key_mod_expo_t* or *ica_rsa_key_crt_t*. They exploit the available cryptographic accelerators and CCA coprocessors.

These functions are declared in: `include/ica_api.h`.

### Using RSA in FIPS mode

For FIPS 140-3 compliance, RSA key lengths are limited to 2048 bits and higher. You can display the available RSA key sizes on your system using the **icainfo** utility:

```
# icainfo -r
RSA key lengths: 2048 ... 4096 bits. /* minimum RSA key length 2048 in FIPS mode
Built-in FIPS support: FIPS 140-3 mode active.
```

## ica_rsa_mod_expo

### Purpose

Performs an RSA encryption or decryption operation using a key in modulus/exponent format.

### Comments

Make sure that your message is padded before using this function.

### Format

```
unsigned int ica_rsa_mod_expo(ica_adapter_handle_t adapter_handle,
  unsigned char *input_data,
  ica_rsa_key_mod_expo_t *rsa_key,
  const unsigned char *output_data);
```

### Required hardware support

Cryptographic accelerators or CCA coprocessors.

### Parameters

**ica_adapter_handle_t adapter_handle**
Pointer to a previously opened device handle.

**const unsigned char *input_data**
Pointer to the input data to be encrypted or decrypted. This data must be in big endian format. Make sure that the input data is not longer than the bit length of the key. The byte length for the input data and the key must be the same. Right align the input data inside the data block.

**ica_rsa_key_mod_expo_t *rsa_key**
Pointer to the key to be used, in modulus/exponent format.

**unsigned char *output_data**
Pointer to the location where the output results are to be placed. This buffer has to be at least the same size as *input_data* and therefore at least the same size as the size of the modulus.

### Return codes

**0**
Success

**EPERM**

Used RSA key is > 4K.

For return codes indicating exceptions, see "Return codes" on page 138.

### ica_rsa_crt

#### Purpose

Performs an RSA encryption or decryption operation using a key in CRT format.

#### Comments

Make sure that your message is padded before using this function.

#### Format

```
unsigned int ica_rsa_crt(ica_adapter_handle_t adapter_handle,
  unsigned char *input_data,
  ica_rsa_key_crt_t *rsa_key,
  const unsigned char *output_data);
```

#### Required hardware support

Cryptographic accelerators or CCA coprocessors.

#### Parameters

**ica_adapter_handle_t adapter_handle**
Pointer to a previously opened device handle.

**const unsigned char *input_data**
Pointer to the input data to be encrypted or decrypted. This data must be in big endian format. Make sure that the input data is not longer than the bit length of the key. The byte length for the input data and the key must be the same. Right align the input data inside the data block.

**ica_rsa_key_crt_t *rsa_key**
Pointer to the key to be used, in CRT format.

**unsigned char *output_data**
Pointer to the location where the output results are to be placed. This buffer must be as large as the *input_data*, and as large as the length of the *modulus* specified in *rsa_key*.

#### Return codes

**0**

Success

**EPERM**

Used RSA key is > 4K.

For return codes indicating exceptions, see "Return codes" on page 138.

## Elliptic curve cryptography (ECC) functions

Elliptic curve cryptography (ECC) is an encryption technique that provides public key encryption based on elliptic curves. Compared to RSA, it achieves the same security level with much smaller keys. The mathematical background of ECC is described in RFC 6090 (*https://datatracker.ietf.org/doc/html/rfc6090*). The use of ECC in SSL/TLS is described in RFC 4492 (*https://datatracker.ietf.org/doc/html/rfc4492*).

The ECC functions make use of the ECC support of the Crypto Express4S feature or later in CCA coprocessor mode. They require a minimum CCA firmware level of 4.2 on the coprocessor.

These functions are declared in: `include/ica_api.h`.

You can use the **`icainfo`** utility with option `-c` to list all elliptic curves that are supported by libica on your current system configuration. The availability of curves is, for example, dependent from whether cryptographic coprocessors in CCA mode are available, whether OpenSSL is in FIPS mode, or whether the whole system is in FIPS mode. For further information, see "icainfo - Show available libica functions" on page 139.

## Create an elliptic curve (EC) key

An EC key pair consists of a scalar (D) and a point (X,Y), which lies on the related elliptic curve. Hereby, D is the private part and (X,Y) is the public part of the key.

The value of the private key D is specified by an octet string whose length depends on the domain parameters of the related elliptic curve. The public key (X,Y) can be derived from D and the curve's domain parameters.

So an EC key pair is specified either by

- the curve and the D-value, or
- the curve-ID (NID value), D-value, and (X,Y).

In libica, an EC key pair is always specified by (NID, D, (X,Y)). The corresponding data type in libica is `ICA_EC_KEY`.

An `ICA_EC_KEY` object is called a public EC key, if (X,Y) is specified, but D is not specified. An `ICA_EC_KEY` object is called a private EC key if D is specified, and optionally also (X,Y).

A public EC key may be given in compressed form, which means that only the X-value is provided. The missing Y-value can be recalculated from the curve-ID (NID value), D, and X. However, libica does not support compressed public EC keys.

## Calculate the Diffie-Hellman (DH) shared secret

In SSL/TLS, ECC is used together with the Diffie-Hellman key agreement protocol that allows two parties (A and B), each having an elliptic curve public/private key pair, to establish a shared secret (z) over an insecure channel. This shared secret may be directly used as a key, or to derive another key. The length of z is equal to the length of D. Unlike to plain RSA-based SSL/TLS key exchange, the DH shared secret (z-value) is not part of the SSL/TLS connection and therefore provides forward secrecy.

## Create or verify an ECDSA signature

The Elliptic Curve Digital Signature Algorithm (ECDSA) is a variant of the Digital Signature Algorithm (DSA) which uses elliptic curve cryptography. Given data is signed with an ECC private key and signature verification is done with an ECC public key. Signing given data using ECDSA results in different signatures when repeating the process, because the algorithm involves a random value (k). This random value is created internally by the signature creation process and is re-calculated when verifying the ECDSA signature.

An ECDSA signature is a tuple of two numbers (`r,s`). In libica, an ECDSA signature has always an even length, and `r` is given by the first half, and `s` by the second half of the signature. In some cases, for example, using the secp521 curve, `r` or `s` may have 65 or 66 bytes. In libica, additional 0x00 bytes are padded at the front in such cases to enforce that `r` and `s` have the same length as D.

### Using ECC in FIPS mode

For FIPS 140-3 compliance, only a subset of elliptic curves is available: p256, p384, p521. All other curves, including Brainpool curves, Edwards curves (ED25519 and ED448) and Montgomery curves (X25519 and X448) are blocked. The three FIPS compliant curves are only available via CPACF and therefore require MSA9 (IBM z15 or later). On older machines, ECC via CPACF is not available. You can display the list of available curves on your system using the **icainfo** utility. The following screen shot is an example from an IBM z15 system running in FIPS mode:

```
# icainfo -c
-------------------------------------------------------
                 |         hardware        |
        EC curve |   dynamic  |   static   |  software
                 |            |  (msa=09)  |
-----------------+------------+------------+-----------
      prime256v1 |     no     |    yes     |      -
       secp384r1 |     no     |    yes     |      -
       secp521r1 |     no     |    yes     |      -
-------------------------------------------------------
Built-in FIPS support: FIPS 140-3 mode active.
```

In column **hardware - static**, which indicates CPACF support, the current MSA-level is displayed.

## ica_ec_key_new

### Purpose

Creates an `ICA_EC_KEY` data structure for a new elliptic curve key.

### Format

```
ICA_EC_KEY* ica_ec_key_new(unsigned int nid,
   unsigned int *privlen);
```

### Required hardware support

None.

### Parameters

**unsigned int nid**

The identifier of the elliptic curve, on which the new key (`ICA_EC_KEY`) shall be based. These identifiers are defined by OpenSSL.

| NID value | NID name (OpenSSL) | Elliptic curve | D length (bytes) |
|---|---|---|---|
| 409 | NID_X9_62_prime192v | secp192r1 | 24 |
| 713 | NID_secp224r1 | secp224r1 | 28 |
| 415 | NID_X9_62_prime256v1 | secp256r1 | 32 |
| 715 | NID_secp384r1 | secp384r1 | 48 |
| 716 | NID_secp521r1 | secp521r1 | 66 |
| 921 | NID_brainpoolP160r1 | brainpoolP160r1 | 20 |
| 923 | NID_brainpoolP192r1 | brainpoolP192r1 | 24 |
| 925 | NID_brainpoolP224r1 | brainpoolP224r1 | 28 |

| NID value | NID name (OpenSSL) | Elliptic curve | D length (bytes) |
|---|---|---|---|
| 927 | NID_brainpoolP256r1 | brainpoolP256r1 | 32 |
| 929 | NID_brainpoolP320r1 | brainpoolP320r1 | 40 |
| 931 | NID_brainpoolP384r1 | brainpoolP384r1 | 48 |
| 933 | NID_brainpoolP512r1 | brainpoolP512r1 | 64 |

**unsigned int *privlen**

Pointer to an unsigned integer buffer where the length of the private D value of the key (ICA_EC_KEY) is returned.

**Note:** The lengths of X and Y are the same as the length of D. Therefore, the public key (X,Y) has twice the length of D. Also, an ECDSA signature has twice the length of D.

### Return codes

Returns a pointer to the opaque **ICA_EC_KEY** structure if successful.

Returns **NULL** if no memory could be allocated.

For return codes indicating exceptions, see “Return codes” on page 138.

## ica_ec_key_init

### Purpose

Initializes an ICA_EC_KEY data structure with given private (D) or public key values (X,Y) or both. D may be NULL, if no private key value shall be specified. X and Y may both be NULL, if no public key shall be specified. If X is specified, also Y must be specified, and vice versa.

### Format

```
int ica_ec_key_init(const unsigned char *X,
  const unsigned char *Y,
  const unsigned char *D,
  ICA_EC_KEY *key);
```

### Required hardware support

None.

### Parameters

**const unsigned char *X**

Pointer to the public X value that shall be assigned to the ICA_EC_KEY object.

**const unsigned char *Y**

Pointer to the public Y value that shall be assigned to the ICA_EC_KEY object.

**const unsigned char *D**

Pointer to the private D value that shall be assigned to the ICA_EC_KEY object.

**ICA_EC_KEY *key**

Pointer to a previously allocated ICA_EC_KEY data structure.

### Return codes

**0**
: Success

**EPERM**
: If the EC curve is not supported in this environment.

For return codes indicating exceptions, see “Return codes” on page 138.

## ica_ec_key_generate

### Purpose

Generates private and public ECC key values for a given `ICA_EC_KEY` data structure.

**Note:** In FIPS mode (140-2 and later), ECC key generation is performed by OpenSSL, because this ensures that the generated keys satisfy the FIPS requirements.

### Format

```
int ica_ec_key_generate(ica_adapter_handle_t adapter_handle,
    ICA_EC_KEY *key);
```

### Required hardware support

At least, a Crypto Express4S CCA coprocessor is required (CEX4C or later).

### Parameters

**ica_adapter_handle_t adapter_handle**
: Pointer to a previously opened device handle.

**ICA_EC_KEY *key**
: Pointer to a previously allocated `ICA_EC_KEY` data structure.

### Return codes

**0**
: Success

**EINVAL**
: If at least one invalid parameter is given.

**ENOMEM**
: If memory could not be allocated.

**EFAULT**
: If an internal processing error occurred.

**EPERM**
: If the EC curve is not supported in this environment.

For return codes indicating exceptions, see “Return codes” on page 138.

## ica_ec_key_free

### Purpose

Frees an `ICA_EC_KEY` data structure.

### Format

```
void ica_ec_key_free(ICA_EC_KEY *key);
```

### Required hardware support

None.

### Parameters

**ICA_EC_KEY *key**
Pointer to an ICA_EC_KEY data structure.

### Return codes

None.

## ica_ecdh_derive_secret

### Purpose

Calculates the Diffie-Hellman shared secret (z value) of a first given private ICA_EC_KEY data structure (with given D value) and a second given public ICA_EC_KEY data structure (with given X and Y values).

### Format

```
int ica_ecdh_derive_secret(ica_adapter_handle_t adapter_handle,
  const ICA_EC_KEY   *privkey_A,
  const ICA_EC_KEY   *pubkey_B,
  unsigned char      *z,
  unsigned int       z_length);
```

### Required hardware support

- At least, a Crypto Express4S CCA coprocessor is required (CEX4C or later).
- MSA9 (IBM z15 or later) for ECDH and ECDSA support via CPACF for these elliptic curves: p256, p384, p521.

### Parameters

**ica_adapter_handle_t adapter_handle**
Pointer to a previously opened device handle.

**const ICA_EC_KEY *privkey_A**
A pointer to a private ICA_EC_KEY object, initialized via **ica_ec_key_init** or **ica_ec_key_generate**.

**const ICA_EC_KEY *pubkey_B**
A pointer to a public ICA_EC_KEY object, initialized via **ica_ec_key_init** or **ica_ec_key_generate**.

**unsigned char *z**
Pointer to a writable buffer where the shared secret (z) is returned.

**unsigned int z_length**
The length in bytes of the z buffer. This length must be greater or equal to **privlen**, as returned when creating the ICA_EC_KEY objects. Both keys are supposed to be based on the same elliptic curve, so both keys have the same length of D, and the same (X,Y).

### Return codes

**0**
Success

**EINVAL**
If at least one invalid parameter is given.

**EFAULT**
If an internal processing error occurred.

**EPERM**
If the EC curve is not supported in this environment.

For return codes indicating exceptions, see "Return codes" on page 138.

## ica_ec_get_public_key

### Purpose

Obtains the public key (X,Y) of the given ICA_EC_KEY data structure.

### Format

```
int ica_ec_key_get_public_key(const ICA_EC_KEY *key,
  unsigned char *q,
  unsigned int  *q_len);
```

### Required hardware support

None.

### Parameters

**const ICA_EC_KEY *key**
Pointer to a previously allocated ICA_EC_KEY data structure.

**unsigned char *q**
Pointer to a writable buffer where (X,Y) is returned.

**unsigned int *q_len**
Pointer to an unsigned integer where the length of (X,Y) in bytes is returned.

### Return codes

**0**
Success

**EINVAL**
If at least one invalid parameter is given.

For return codes indicating exceptions, see "Return codes" on page 138.

## ica_ec_get_private_key

### Purpose

Obtains the private key (D) of the given ICA_EC_KEY data structure.

## Format

```
int ica_ec_key_get_private_key(const ICA_EC_KEY *key,
  unsigned char *d,
  unsigned int  *d_len);
```

## Required hardware support

None.

## Parameters

**const ICA_EC_KEY *key**
Pointer to a previously allocated ICA_EC_KEY data structure.

**unsigned char *d**
Pointer to a writable buffer where D is returned.

**unsigned int *d_len**
Pointer to an unsigned integer where the length of D in bytes is returned.

## Return codes

**0**
Success

**EINVAL**
If at least one invalid parameter is given.

For return codes indicating exceptions, see "Return codes" on page 138.

# ica_ecdsa_sign

## Purpose

Creates an ECDSA signature for the given hashed data using the given private ICA_EC_KEY data structure.

## Format

```
int ica_ecdsa_sign(ica_adapter_handle_t adapter_handle,
  const ICA_EC_KEY    *privkey,
  const unsigned char *data,
  unsigned int         data_length,
  unsigned char       *signature,
  unsigned int         signature_length);
```

## Required hardware support

- At least, a Crypto Express4S CCA coprocessor is required (CEX4C or later).
- MSA9 (IBM z15 or later) for ECDH and ECDSA support via CPACF for these elliptic curves: p256, p384, p521.

## Parameters

**ica_adapter_handle_t adapter_handle**
Pointer to a previously opened device handle.

**const ICA_EC_KEY *privkey**
Pointer to a readable private ICA_EC_KEY object.

**const unsigned char *data**
Pointer to a readable buffer containing the hashed data for which the signature is to be generated.

**unsigned int data_length**
The length of the hashed data. Supported lengths are 20, 28, 32, 48, and 64 bytes.

**unsigned char *signature**
Pointer to a writable buffer where the ECDSA signature is returned.

**unsigned int signature_length**
The length of the buffer. It must be greater or equal to 2***`privlen`** as returned when creating the `ICA_EC_KEY` data structure.

### Return codes

**0**
Success

**EINVAL**
If at least one invalid parameter is given.

**EFAULT**
If an internal processing error occurred.

For return codes indicating exceptions, see "Return codes" on page 138.

## ica_ecdsa_sign_ex

### Purpose

Creates a deterministic ECDSA signature for the given hash data by using the given private `ICA_EC_KEY` data structure and a known **k** value instead of a random value.

**Notes:**

- In FIPS mode, this function is only allowed for internal self-tests. When being called from an application it returns EPERM.
- Creating deterministic signatures is only supported via CPACF on MSA9 or later. Check your **`icainfo [-c]`** output if ECDSA via CPACF is available on your hardware . The function returns EPERM if ECDSA is not supported via CPACF.

### Format

```
int ica_ecdsa_sign_ex(ica_adapter_handle_t adapter_handle,
  const ICA_EC_KEY *privkey,
  const unsigned char *hash,
  unsigned int hash_length,
  unsigned char *signature,
  unsigned int signature_length,
  const unsigned char *k);
```

### Required hardware support

- CPACF with MSA9 (IBM z15 or later) .

### Parameters

**ica_adapter_handle_t adapter_handle**
Pointer to a previously opened device handle.

**const ICA_EC_KEY *privkey**
Pointer to a readable private `ICA_EC_KEY` object.

**const unsigned char *hash**
Pointer to a readable buffer containing the hashed data for which the signature is to be generated.

**unsigned int hash_length**
The length of the hashed data. Supported lengths are 20, 28, 32, 48, and 64 bytes.

**unsigned char *signature**
Pointer to a writable buffer where the ECDSA signature is returned.

**unsigned int signature_length**
The length of the buffer. It must be greater or equal to 2***`privlen`** as returned when creating the `ICA_EC_KEY` data structure.

**unsigned char *k**
Pointer to a readable buffer containing the **k** value, used together with the private key and input hash to create a deterministic signature. This allows to implement known-answer tests using test vectors available from various sources, for example, NIST or RFCs. The length of **k** is expected to be equal to the lengths of the **`r`** and **`s`** parts of the signature.

### Return codes

**0**
Success

**EINVAL**
If at least one invalid parameter is given.

**EIO**
If an internal processing error occurred.

**EPERM**
If ECDSA is not supported via CPACF (MSA9 or later).

For return codes indicating exceptions, see “Return codes” on page 138.

## ica_ecdsa_verify

### Purpose

Verifies an ECDSA signature with the given data using the public `ICA_EC_KEY` data structure.

### Format

```
int ica_ecdsa_verify(ica_adapter_handle_t adapter_handle,
  const ICA_EC_KEY     *pubkey,
  const unsigned char  *data,
  unsigned int          data_length,
  const unsigned char  *signature,
  unsigned int          signature_length);
```

### Required hardware support

- At least, a Crypto Express4S CCA coprocessor is required (CEX4C or later).
- MSA9 (IBM z15 or later) for ECDH and ECDSA support via CPACF for these elliptic curves: p256, p384, p521.

### Parameters

**ica_adapter_handle_t adapter_handle**
Pointer to a previously opened device handle.

**const ICA_EC_KEY *pubkey**
Pointer to a readable public `ICA_EC_KEY` object.

**const unsigned char *data**
Pointer to a readable buffer containing the hashed data for which the signature is to be verified.

**unsigned int data_length**
The length of the hashed data. Supported lengths are 20, 28, 32, 48, and 64 bytes.

**unsigned char *signature**
Pointer to a readable buffer where the ECDSA signature is provided.

**unsigned int signature_length**
The length of the buffer. It must be greater or equal to 2***`privlen`** as returned when creating the `ICA_EC_KEY` data structure.

### Return codes

**0**
Success

**EINVAL**
If at least one invalid parameter is given.

**EIO**
If an internal processing error occurred.

**EFAULT**
If the signature is invalid.

For return codes indicating exceptions, see "Return codes" on page 138.

## ica_x25519_ctx_new

### Purpose

Allocates a new X25519 context and returns its address as output parameter. The context buffer is used by all other `ica_x25519_...` functions as a working area and must not be changed by the application. It must be freed by the `ica_x25519_ctx_del` function when no longer needed.

### Format

```
int ica_x25519_ctx_new(ICA_X25519_CTX **ctx);
```

### Required hardware support

The processor must have the MSA9 facility (STFLE bit 155) installed which is available starting with IBM z15 systems.

### Parameters

**ICA_X25519_CTX **ctx**
Address of a pointer to an X25519 context.

### Return codes

**0**
Success

**-1**
If at least one invalid parameter is given or MSA9 is not available.

For return codes indicating exceptions, see "Return codes" on page 138.

# ica_x448_ctx_new

## Purpose

Allocates a new X448 context and returns its address as output parameter. The context buffer is used by all other `ica_x448_...` functions as a working area and must not be changed by the application. It must be freed by the `ica_x448_ctx_del` function when no longer needed.

## Format

```
int ica_x448_ctx_new(ICA_X448_CTX **ctx);
```

## Required hardware support

The processor must have the MSA9 facility (STFLE bit 155) installed which is available starting with IBM z15 systems.

## Parameters

**ICA_X448_CTX **ctx**
Address of a pointer to an X448 context.

## Return codes

**0**
Success

**-1**
If at least one invalid parameter is given or MSA9 is not available.

For return codes indicating exceptions, see “Return codes” on page 138.

# ica_ed25519_ctx_new

## Purpose

Allocates a new ED25519 context and returns its address as output parameter. The context buffer is used by all other `ica_ed25519_...` functions as a working area and must not be changed by the application. It must be freed by the corresponding `ica_ed25519_ctx_del` function when no longer needed.

## Format

```
int ica_ed25519_ctx_new(ICA_ED25519_CTX **ctx);
```

## Required hardware support

The processor must have the MSA9 facility (STFLE bit 155) installed which is available starting with IBM z15 systems.

## Parameters

**ICA_ED25519_CTX **ctx**
Address of a pointer to an ED25519 context.

### Return codes

**0**
Success

**-1**
If at least one invalid parameter is given or MSA9 is not available.

For return codes indicating exceptions, see "Return codes" on page 138.

## ica_ed448_ctx_new

### Purpose

Allocates a new ED448 context and returns its address as output parameter. The context buffer is used by all other `ica_ed448_...` functions as a working area and must not be changed by the application. It must be freed by the corresponding `ica_ed448_ctx_del` function when no longer needed.

### Format

```
int ica_ed448_ctx_new(ICA_ED448_CTX **ctx);
```

### Required hardware support

The processor must have the MSA9 facility (STFLE bit 155) installed which is available starting with IBM z15 systems.

### Parameters

**ICA_ED448_CTX **ctx**
Address of a pointer to an ED448 context.

### Return codes

**0**
Success

**-1**
If at least one invalid parameter is given or MSA9 is not available.

For return codes indicating exceptions, see "Return codes" on page 138.

## ica_x25519_key_set

### Purpose

Copies the given private and public key values into an X25519 context.

### Format

```
int ica_x25519_key_set(ICA_X25519_CTX *ctx,
  const unsigned char priv[32],
  const unsigned char pub[32]);
```

### Required hardware support

The processor must have the MSA9 facility (STFLE bit 155) installed which is available starting with IBM z15 systems.

### Parameters

**ICA_X25519_CTX *ctx**
Pointer to an X25519 context.

**const unsigned char priv[32]**
Buffer containing the private key for an X25519 context to be copied to that context.

**const unsigned char pub[32]**
Buffer containing the public key for an X25519 context to be copied to that context.

### Return codes

**0**
Success

**-1**
If at least one invalid parameter is given or MSA9 is not available.

For return codes indicating exceptions, see "Return codes" on page 138.

## ica_x448_key_set

### Purpose

Copies the given private and public key values into an X448 context.

### Format

```
int ica_x448_key_set(ICA_X448_CTX *ctx,
  const unsigned char priv[56],
  const unsigned char pub[56]);
```

### Required hardware support

The processor must have the MSA9 facility (STFLE bit 155) installed which is available starting with IBM z15 systems.

### Parameters

**ICA_X448_CTX *ctx**
Pointer to an X448 context.

**const unsigned char priv[56]**
Buffer containing the private key for an X448 context to be copied to that context.

**const unsigned char pub[56]**
Buffer containing the public key for an X448 context to be copied to that context.

### Return codes

**0**
Success

**-1**
If at least one invalid parameter is given or MSA9 is not available.

For return codes indicating exceptions, see "Return codes" on page 138.

# ica_ed25519_key_set

## Purpose

Copies the given private and public key values into an ED25519 context.

## Format

```
int ica_ed25519_key_set(ICA_ED25519_CTX *ctx,
  unsigned char priv[32],
  unsigned char pub[32]);
```

## Required hardware support

The processor must have the MSA9 facility (STFLE bit 155) installed which is available starting with IBM z15 systems.

## Parameters

**ICA_ED25519_CTX *ctx**
Pointer to an ED25519 context.

**unsigned char priv[32]**
Buffer containing the private key for an ED25519 context to be copied to that context.

**unsigned char pub[32]**
Buffer containing the public key for an ED25519 context to be copied to that context.

## Return codes

**0**
Success

**-1**
If at least one invalid parameter is given or MSA9 is not available.

For return codes indicating exceptions, see “Return codes” on page 138.

# ica_ed448_key_set

## Purpose

Copies the given private and public key values into an ED448 context.

## Format

```
int ica_ed448_key_set(ICA_ED448_CTX *ctx,
  const unsigned char priv[57],
  const unsigned char pub[57]);
```

## Required hardware support

The processor must have the MSA9 facility (STFLE bit 155) installed which is available starting with IBM z15 systems.

### Parameters

**ICA_ED448_CTX *ctx**
Pointer to an ED448 context.

**const unsigned char priv[57]**
Buffer containing the private key for an ED448 context to be copied to that context.

**const unsigned char pub[57]**
Buffer containing the public key for an ED448 context to be copied to that context.

### Return codes

**0**
Success

**-1**
If at least one invalid parameter is given or MSA9 is not available.

For return codes indicating exceptions, see "Return codes" on page 138.

## ica_x25519_key_get

### Purpose

Obtain the private and public key values from a given X25519 context.

### Format

```
int ica_x25519_key_get(ICA_X25519_CTX *ctx,
  unsigned char priv[32],
  unsigned char pub[32]);
```

### Required hardware support

The processor must have the MSA9 facility (STFLE bit 155) installed which is available starting with IBM z15 systems.

### Parameters

**ICA_X25519_CTX *ctx**
Pointer to an X25519 context.

**const unsigned char priv[32]**
Buffer receiving the private key of an X25519 context.

**const unsigned char pub[32]**
Buffer receiving the public key of an X25519 context.

### Return codes

**0**
Success

**-1**
If at least one invalid parameter is given, or if MSA9 is not available, or an internal error occurred when deriving the public from the private key.

For return codes indicating exceptions, see "Return codes" on page 138.

## ica_x448_key_get

### Purpose

Obtain the private and public key values from a given X448 context.

### Format

```
int ica_x448_key_get(ICA_X448_CTX *ctx,
  const unsigned char priv[56],
  const unsigned char pub[56]);
```

### Required hardware support

The processor must have the MSA9 facility (STFLE bit 155) installed which is available starting with IBM z15 systems.

### Parameters

**ICA_X448_CTX *ctx**
Pointer to an X448 context.

**const unsigned char priv[56]**
Buffer receiving the private key of an X448 context.

**const unsigned char pub[56]**
Buffer receiving the public key of an X448 context.

### Return codes

**0**
Success

**-1**
If at least one invalid parameter is given, or if MSA9 is not available, or an internal error occurred when deriving the public from the private key.

For return codes indicating exceptions, see “Return codes” on page 138.

## ica_ed25519_key_get

### Purpose

Copies the private and public key from the context.

### Format

```
int ica_ed25519_key_get(ICA_ED25519_CTX *ctx,
  unsigned char priv[32],
  unsigned char pub[32]);
```

### Required hardware support

The processor must have the MSA9 facility (STFLE bit 155) installed which is available starting with IBM z15 systems.

### Parameters

**ICA_ED25519_CTX *ctx**
Pointer to an ED25519 context.

**unsigned char priv[32]**
Buffer receiving the private key of an ED25519 context.

**unsigned char pub[32]**
Buffer receiving the public key of an ED25519 context.

### Return codes

**0**
Success

**-1**
If at least one invalid parameter is given, or if MSA9 is not available, or an internal error occurred when deriving the public from the private key.

For return codes indicating exceptions, see "Return codes" on page 138.

## ica_ed448_key_get

### Purpose

Copies the private and public key from the context.

### Format

```
int ica_ed448_key_get(ICA_ED448_CTX *ctx,
  unsigned char priv[57],
  unsigned char pub[57]);
```

### Required hardware support

The processor must have the MSA9 facility (STFLE bit 155) installed which is available starting with IBM z15 systems.

### Parameters

**ICA_ED448_CTX *ctx**
Pointer to an ED448 context.

**unsigned char priv[57]**
Buffer receiving the private key of an ED448 context.

**unsigned char pub[57]**
Buffer receiving the public key of an ED448 context.

### Return codes

**0**
Success

**-1**
If at least one invalid parameter is given, or if MSA9 is not available, or an internal error occurred when deriving the public from the private key.

For return codes indicating exceptions, see "Return codes" on page 138.

## ica_x25519_key_gen

### Purpose

Generates a private and a public key value for a given X25519 context.

### Format

```
int ica_x25519_key_gen(ICA_X25519_CTX *ctx);
```

### Required hardware support

The processor must have the MSA9 facility (STFLE bit 155) installed which is available starting with IBM z15 systems.

### Parameters

**ICA_X25519_CTX *ctx**
Pointer to an X25519 context.

### Return codes

**0**
Success

**-1**
If at least one invalid parameter is given or MSA9 is not available.

For return codes indicating exceptions, see “Return codes” on page 138.

## ica_x448_key_gen

### Purpose

Generates a private and a public key value for a given X448 context.

### Format

```
int ica_x448_key_gen(ICA_X448_CTX *ctx);
```

### Required hardware support

The processor must have the MSA9 facility (STFLE bit 155) installed which is available starting with IBM z15 systems.

### Parameters

**ICA_X448_CTX *ctx**
Pointer to an X448 context.

### Return codes

**0**
Success

**-1**
If at least one invalid parameter is given or MSA9 is not available.

For return codes indicating exceptions, see “Return codes” on page 138.

## ica_ed25519_key_gen

### Purpose

Generates a private and a public key value for a given ED25519 context.

### Format

```
int ica_ed25519_key_gen(ICA_ED25519_CTX *ctx);
```

### Required hardware support

The processor must have the MSA9 facility (STFLE bit 155) installed which is available starting with IBM z15 systems.

### Parameters

**ICA_ED25519_CTX *ctx**
Pointer to an ED25519 context.

### Return codes

**0**
Success

**-1**
If at least one invalid parameter is given or MSA9 is not available.

For return codes indicating exceptions, see “Return codes” on page 138.

## ica_ed448_key_gen

### Purpose

Generates a private and a public key value for a given ED448 context.

### Format

```
int ica_ed448_key_gen(ICA_ED448_CTX *ctx);
```

### Required hardware support

The processor must have the MSA9 facility (STFLE bit 155) installed which is available starting with IBM z15 systems.

### Parameters

**ICA_ED448_CTX *ctx**
Pointer to an ED448 context.

### Return codes

**0**
Success

**-1**

If at least one invalid parameter is given or MSA9 is not available.

For return codes indicating exceptions, see “Return codes” on page 138.

# ica_x25519_derive

## Purpose

Derive a shared secret between the private key of party A stored in the context, and the given public key of party B. Requires the context to hold the private key of party A.

## Format

```
int ica_x25519_key_derive(ICA_X25519_CTX *ctx,
  unsigned char shared_secret[32],
  const unsigned char peer_pub[32]);
```

## Required hardware support

The processor must have the MSA9 facility (STFLE bit 155) installed which is available starting with IBM z15 systems.

## Parameters

**ICA_X25519_CTX *ctx**

Pointer to an X25519 context.

**unsigned char shared_secret[32]**

Buffer to return the derived shared secret between party A and party B.

**const unsigned char peer_pub[32]**

Buffer containing the given public key of party B as input.

## Return codes

**0**

Success

**-1**

If at least one invalid parameter is given or MSA9 is not available, or the key derivation failed.

For return codes indicating exceptions, see “Return codes” on page 138.

# ica_x448_derive

## Purpose

Derives a shared secret between the private key of party A stored in the context, and the given public key of party B. Requires the context to hold the private key of party A.

## Format

```
int ica_x448_derive(ICA_X448_CTX *ctx,
  unsigned char shared_secret[56],
  const unsigned char peer_pub[56]);
```

### Required hardware support

The processor must have the MSA9 facility (STFLE bit 155) installed which is available starting with IBM z15 systems.

### Parameters

**ICA_X448_CTX *ctx**
Pointer to an X448 context.

**unsigned char shared_secret[56]**
Buffer to return the derived shared secret between party A and party B.

**const unsigned char peer_pub[56]**
Buffer containing the given public key of party B as input.

### Return codes

**0**
Success

**-1**
If at least one invalid parameter is given or MSA9 is not available, or the key derivation failed.

For return codes indicating exceptions, see "Return codes" on page 138.

## ica_ed25519_sign

### Purpose

Signs the given input message with the private key contained in the context and returns the 64-byte ed25519 signature.

### Format

```
int ica_ed25519_sign(ICA_ED25519_CTX *ctx,
  unsigned char sig[64],
  const unsigned char *msg,
  size_t msglen);
```

### Required hardware support

The processor must have the MSA9 facility (STFLE bit 155) installed which is available starting with IBM z15 systems.

### Parameters

**ICA_ED25519_CTX *ctx**
Pointer to an ED25519 context.

**unsigned char sig[64]**
Buffer containing the returned signature.

**const unsigned char *msg**
Buffer containing the input message to be signed.

**size_t msglen**
Length in bytes of the input message to be signed.

### Return codes

**0**

Success

**-1**

If at least one invalid parameter is given or MSA9 is not available.

For return codes indicating exceptions, see “Return codes” on page 138.

## ica_ed448_sign

### Purpose

Signs the given input message with the private key contained in the context and returns the 114-byte ed448 signature.

### Format

```
int ica_ed448_sign(ICA_ED448_CTX *ctx,
  unsigned char sig[114],
  const unsigned char *msg,
  size_t msglen);
```

### Required hardware support

The processor must have the MSA9 facility (STFLE bit 155) installed which is available starting with IBM z15 systems.

### Parameters

**ICA_ED448_CTX *ctx**

Pointer to an ED448 context.

**unsigned char sig[114]**

Buffer containing the returned signature.

**const unsigned char *msg**

Buffer containing the input message to be signed.

**size_t msglen**

Length in bytes of the input message to be signed.

### Return codes

**0**

Success

**-1**

If at least one invalid parameter is given or MSA9 is not available.

For return codes indicating exceptions, see “Return codes” on page 138.

## ica_ed25519_verify

### Purpose

Verifies the given ED25519 signature using the public key from the context against the given message. Returns 0 if the signature is valid, returns -1 if the signature is invalid or an internal error occurred. If the context does not contain the public key, it is internally derived from the private key in the context.

### Format

```
int ica_ed25519_verify(ICA_ED25519_CTX *ctx,
  unsigned char sig[64],
  const unsigned char *msg,
  size_t msglen);
```

### Required hardware support

The processor must have the MSA9 facility (STFLE bit 155) installed which is available starting with IBM z15 systems.

### Parameters

**ICA_ED25519_CTX *ctx**
Pointer to an ED25519 context.

**unsigned char sig[64]**
Buffer containing the signature as input.

**const unsigned char *msg**
Buffer containing the message as input.

**size_t msglen**
Length of the input message to be verified.

### Return codes

**0**
Success. Signature is OK.

**-1**
If at least one invalid parameter is given, or MSA9 is not available. Also, if deriving the public from the private key fails and if the signature could not be correctly verified.

For return codes indicating exceptions, see “Return codes” on page 138.

## ica_ed448_verify

### Purpose

Verifies the given ED448 signature using the public key from the context against the given message. Returns 0 if the signature is valid, returns -1 if the signature is invalid or an internal error occurred. If the context does not contain the public key, it is internally derived from the private key in the context.

### Format

```
int ica_ed448_verify(ICA_ED448_CTX *ctx,
  unsigned char sig[114],
  const unsigned char *msg,
  size_t msglen);
```

### Required hardware support

The processor must have the MSA9 facility (STFLE bit 155) installed which is available starting with IBM z15 systems.

### Parameters

**ICA_ED448_CTX *ctx**
Pointer to an ED448 context.

**unsigned char sig[114]**
Buffer containing the input signature.

**const unsigned char *msg**
Buffer containing the message as input.

**size_t msglen**
Length in bytes of the input message to be verified.

### Return codes

**0**
Success. Signature is OK.

**-1**
If at least one invalid parameter is given, or MSA9 is not available. Also, if deriving the public from the private key fails and if the signature could not be correctly verified.

For return codes indicating exceptions, see “Return codes” on page 138.

## ica_x25519_ctx_del

### Purpose

Deallocates a previously allocated X25519 context. Its sensitive data is erased.

### Format

```
int ica_x25519_ctx_del(ICA_X25519_CTX **ctx);
```

### Required hardware support

The processor must have the MSA9 facility (STFLE bit 155) installed which is available starting with IBM z15 systems.

### Parameters

**ICA_X25519_CTX **ctx**
Address of a pointer to the X25519 context to be deleted.

### Return codes

**0**
Success

**-1**
If at least one invalid parameter is given or MSA9 is not available.

For return codes indicating exceptions, see “Return codes” on page 138.

## ica_x448_ctx_del

### Purpose

Deallocates a previously allocated X448 context. Its sensitive data is erased.

### Format

```
int ica_x448_ctx_del(ICA_X448_CTX **ctx);
```

### Required hardware support

The processor must have the MSA9 facility (STFLE bit 155) installed which is available starting with IBM z15 systems.

### Parameters

**ICA_X448_CTX **ctx**
Address of a pointer to the X448 context to be deleted.

### Return codes

**0**
Success

**-1**
If at least one invalid parameter is given or MSA9 is not available.

For return codes indicating exceptions, see "Return codes" on page 138.

## ica_ed25519_ctx_del

### Purpose

Deallocates a previously allocated ED25519 context. Its sensitive data is erased.

### Format

```
int ica_ed25519_ctx_del(ICA_ED25519_CTX **ctx);
```

### Required hardware support

The processor must have the MSA9 facility (STFLE bit 155) installed which is available starting with IBM z15 systems.

### Parameters

**ICA_ED25519_CTX **ctx**
Address of a pointer to the ED25519 context to be deleted.

### Return codes

**0**
Success

**-1**
If at least one invalid parameter is given or MSA9 is not available.

For return codes indicating exceptions, see "Return codes" on page 138.

## ica_ed448_ctx_del

### Purpose

Deallocates a previously allocated ED448 context. Its sensitive data is erased.

### Format

```
int ica_ed448_ctx_del(ICA_ED448_CTX **ctx);
```

### Required hardware support

The processor must have the MSA9 facility (STFLE bit 155) installed which is available starting with IBM z15 systems.

### Parameters

**ICA_ED448_CTX **ctx**

Address of a pointer to the ED448 context to be deleted.

### Return codes

**0**

Success

**-1**

If at least one invalid parameter is given or MSA9 is not available.

For return codes indicating exceptions, see “Return codes” on page 138.

## AES functions

These functions perform encryption and decryption or computation or verification of message authentication codes using an AES key. Supported key lengths are 16, 24 or 32 bytes for AES-128, AES-192 and AES-256 respectively. The cipher block size for AES is 16 bytes.

These functions are declared in: `include/ica_api.h`.

To securely apply AES encryption to messages that are longer than the cipher block size, modes of operation can be used to chain multiple encryption, decryption, or authentication operations. Most modes of operation require an initialization vector as additional input.

As long as the messages are encrypted or decrypted using such a mode of operation, have a size that is a multiple of a particular block size (mostly the cipher block size), the functions encrypting or decryption according to a mode of operation also compute an output vector. The output vector can be used as the initialization vector of a chained encryption or decryption operation in the same mode with the same block size and the same key.

When decrypting a cipher text, the mode of operation, the key, the initialization vector (if applicable), and for `ica_aes_cfb`, the *lcfb* value used for the decryption function must match the corresponding settings of the encryption function that transformed the plain text into cipher text.

### AES API functions exploiting the KMA instruction

libica offers an enhanced API for the AES cipher in GCM block cipher mode. It consists of six API functions that exploit the cipher message with authentication (KMA) instruction. This KMA instruction is part of the message-security-assist extension 8 (MSA 8) and runs on the CPACF starting with z14 processors.

GCM API functions provided by libica earlier than version 3.2 also use the new KMA instruction on z14 processors. However, the enhanced GCM APIs offer advantages concerning usability and performance. Therefore, consider to use these APIs instead of the existing ones in all of your applicable applications.

You find the descriptions of the enhanced GCM APIs in the following topics:

- "ica_aes_gcm_kma_ctx_new" on page 91
- "ica_aes_gcm_kma_ctx_free" on page 92
- "ica_aes_gcm_kma_init" on page 92
- "ica_aes_gcm_kma_update" on page 95
- "ica_aes_gcm_kma_get_tag" on page 97
- "ica_aes_gcm_kma_verify_tag" on page 98

# ica_aes_cbc

## Purpose

Encrypt or decrypt data with an AES key using Cipher Block Chaining (CBC) mode, as described in NIST Special Publication 800-38A Chapter 6.2.

## Format

```
unsigned int ica_aes_cbc(const unsigned char *in_data,
  unsigned char *out_data,
  unsigned long data_length,
  const unsigned char *key,
  unsigned int key_length,
  unsigned char *iv,
  unsigned int direction);
```

## Required hardware support

KMC-AES-128, KMC-AES-192, or KMC-AES-256

## Parameters

**const unsigned char *in_data**
Pointer to a readable buffer that contains the message to be encrypted or decrypted. The size of the message in bytes is *data_length*. The size of this buffer must be at least as large as *data_length*.

**unsigned char *out_data**
Pointer to a writable buffer to contain the resulting encrypted or decrypted message. The size of this buffer in bytes must be at least as large as *data_length*.

**unsigned long data_length**
Length in bytes of the message to be encrypted or decrypted, which resides at the beginning of *in_data*. *data_length* must be a multiple of the cipher block size (a multiple of 16 for AES).

**const unsigned char *key**
Pointer to a valid AES key.

**unsigned int key_length**
Length in bytes of the AES key. Supported sizes are 16, 24, and 32, for AES-128, AES-192, and AES-256 respectively. Therefore, you can use the definitions: `AES_KEY_LEN128`, `AES_KEY_LEN192`, and `AES_KEY_LEN256`.

**unsigned char *iv**
Pointer to a valid initialization vector of the same size as the cipher block in bytes. This vector is overwritten during the function. The result value in *iv* can be used as the initialization vector for a chained `ica_aes_cbc` or `ica_aes_cbc_cs` call with the same key.

**unsigned int direction**

**0**
Use the decrypt function.

**1**
Use the encrypt function.

### Return codes

**0**
Success

For return codes indicating exceptions, see “Return codes” on page 138.

## ica_aes_cbc_cs

### Purpose

Encrypt or decrypt data with an AES key using Cipher Block Chaining with Ciphertext Stealing (CBC-CS) mode, as described in NIST Special Publication 800-38A Chapter 6.2, and the Addendum to NIST Special Publication 800-38A on *Recommendation for Block Cipher Modes of Operation: Three Variants of Ciphertext Stealing for CBC Mode*.

`ica_aes_cbc_cs` can be used to encrypt or decrypt the last chunk of a message consisting of multiple chunks, where all chunks except the last one are encrypted or decrypted by chained calls to `ica_aes_cbc`. To do this, the resulting *iv* of the last call to `ica_aes_cbc` is fed into the *iv* of the `ica_aes_cbc_cs` call, provided that the chunk is greater than the cipher block size (greater than 16 bytes for AES).

### Format

```
unsigned int ica_aes_cbc_cs(const unsigned char *in_data,
  unsigned char *out_data,
  unsigned long data_length,
  const unsigned char *key,
  unsigned int key_length,
  unsigned char *iv,
  unsigned int direction,
  unsigned int variant);
```

### Required hardware support

KMC-AES-128, KMC-AES-192 or KMC-AES-256

### Parameters

**const unsigned char *in_data**
Pointer to a readable buffer that contains the message to be encrypted or decrypted. The size of the message in bytes is *data_length*. The size of this buffer must be at least as large as *data_length*.

**unsigned char *out_data**
Pointer to a writable buffer to contain the resulting encrypted or decrypted message. The size of this buffer in bytes must be at least as large as *data_length*.

**unsigned long data_length**
Length in bytes of the message to be encrypted or decrypted, which resides at the beginning of *in_data*. *data_length* must be greater than or equal to the cipher block size (16 bytes for AES).

**const unsigned char *key**
Pointer to a valid AES key.

**unsigned int key_length**

Length in bytes of the AES key. Supported sizes are 16, 24, and 32, for AES-128, AES-192, and AES-256 respectively. . Therefore, you can use the definitions: AES_KEY_LEN128, AES_KEY_LEN192, and AES_KEY_LEN256.

**unsigned char *iv**

Pointer to a valid initialization vector of cipher block size number of bytes. This vector is overwritten during the function. For *variant* equal to 1 or *variant* equal to 2, the result value in *iv* can be used as the initialization vector for a chained `ica_aes_cbc` or `ica_aes_cbc_cs` call with the same key, if *data_length* is a multiple of the cipher block size.

**unsigned int direction**

**0**

Use the decrypt function.

**1**

Use the encrypt function.

**unsigned int variant**

**1**

Use variant CBC-CS1 of the Addendum to NIST Special Publication 800-38A to encrypt or decrypt the message: always keep last two blocks in order.

**2**

Use variant CBC-CS2 of the Addendum to NIST Special Publication 800-38A to encrypt or decrypt the message: switch order of the last two blocks if *data_length* is not a multiple of the cipher block size (a multiple of 16 bytes for AES).

**3**

Use variant CBC-CS3 of the Addendum to NIST Special Publication 800-38A to encrypt or decrypt the message: always switch order of the last two blocks.

### Return codes

**0**

Success

For return codes indicating exceptions, see “Return codes” on page 138.

## ica_aes_ccm

### Purpose

Encrypt and authenticate or decrypt data and check authenticity of data with an AES key using Counter with Cipher Block Chaining Message Authentication Code (CCM) mode, as described in NIST Special Publication 800-38C. Formatting and counter functions are implemented according to NIST 800-38C Appendix A.

### Format

```
unsigned int ica_aes_ccm(unsigned char *payload,
  unsigned long payload_length,
  unsigned char *ciphertext_n_mac,
  unsigned int mac_length,
  const unsigned char *assoc_data,
  unsigned long assoc_data_length,
  const unsigned char *nonce,
  unsigned int nonce_length,
  const unsigned char *key,
  unsigned int key_length,
  unsigned int direction);
```

## Required hardware support

KMCTR-AES-128, KMCTR-AES-192, or KMCTR-AES-256
KMAC-AES-128, KMAC-AES-192, or KMAC-AES-256

## Parameters

**unsigned char *payload**
Pointer to a buffer of size greater than or equal to *payload_length* bytes. If *direction* is equal to 1, the payload buffer must be readable and contain a payload message of size *payload_length* to be encrypted. If direction is equal to 0, the payload buffer must be writable. If the authentication verification succeeds, the decrypted message in the most significant *payload_length* bytes of *ciphertext_n_mac* is written to this buffer. Otherwise, the contents of this buffer is undefined.

**unsigned long payload_length**
Length in bytes of the message to be encrypted or decrypted. This value can be 0 unless *assoc_data_length* is equal to 0.

**unsigned char *ciphertext_n_mac**
Pointer to a buffer of size greater than or equal to *payload_length* plus *mac_length* bytes. If *direction* is equal to 1, the buffer must be writable and the encrypted message from *payload* followed by the message authentication code for the nonce, the payload, and associated data are written to that buffer. If direction is equal to 0, then the buffer is readable and contains an encrypted message of length *payload_length* followed by a message authentication code of length *mac_length*.

**unsigned int mac_length**
Length in bytes of the message authentication code. Valid values are: 4, 6, 8, 10, 12, and 16.

**const unsigned char *assoc_data**
Pointer to a readable buffer of size greater than or equal to *assoc_data_length* bytes. The associated data in the most significant *assoc_data_length* bytes is subject to the authentication code computation, but is not encrypted.

**unsigned long assoc_data_length**
Length of the associated data in *assoc_data*. This value can be 0 unless *payload_length* is equal to 0.

**const unsigned char *nonce**
Pointer to readable buffer of size greater than or equal to *nonce_length* bytes, which contains a nonce (number used once) of size *nonce_length* bytes.

**unsigned int nonce_length**
Length of the *nonce* in bytes. Valid values are greater than 6 and less than 14.

**const unsigned char *key**
Specifies a pointer to a valid AES key.

**unsigned int key_length**
Length in bytes of the AES key. Supported sizes are 16, 24, and 32 for AES-128, AES-192 and AES-256 respectively. Therefore, you can use the definitions: `AES_KEY_LEN128`, `AES_KEY_LEN192`, and `AES_KEY_LEN256`.

**unsigned int direction**

**0**
Use the decrypt function.

**1**
Use the encrypt function.

## Return codes

**0**
Success

**EFAULT**
If *direction* is equal to 0 and the verification of the message authentication code fails.

For return codes indicating exceptions, see “Return codes” on page 138.

## ica_aes_cfb

### Purpose

Encrypt or decrypt data with an AES key using Cipher Feedback (CFB) mode, as described in NIST Special Publication 800-38A Chapter 6.3.

### Format

```
unsigned int ica_aes_cfb(const unsigned char *in_data,
  unsigned char *out_data,
  unsigned long data_length,
  const unsigned char *key,
  unsigned int key_length,
  unsigned char *iv,
  unsigned int lcfb,
  unsigned int direction);
```

### Required hardware support

KMF-AES-128, KMF-AES-192, or KMF-AES-256

### Parameters

**const unsigned char *in_data**

Pointer to a readable buffer that contains the message to be encrypted or decrypted. The size of the message in bytes is *data_length*. The size of this buffer must be at least as large as *data_length*.

**unsigned char *out_data**

Pointer to a writable buffer to contain the resulting encrypted or decrypted message. The size of this buffer in bytes must be at least as large as *data_length*.

**unsigned long data_length**

Length in bytes of the message to be encrypted or decrypted, which resides at the beginning of *in_data*.

**const unsigned char *key**

Pointer to a valid AES key.

**unsigned int key_length**

Length in bytes of the AES key. Supported sizes are 16, 24, and 32, for AES-128, AES-192, and AES-256 respectively. Therefore, you can use the definitions: `AES_KEY_LEN128`, `AES_KEY_LEN192`, and `AES_KEY_LEN256`.

**unsigned char *iv**

Pointer to a valid initialization vector of the same size as the cipher block in bytes (16 bytes for AES). This vector is overwritten during the function. The result value in *iv* can be used as the initialization vector for a chained `ica_aes_cfb` call with the same key, if the *data_length* in the preceding call is a multiple of *lcfb*.

**unsigned int lcfb**

Length in bytes of the cipher feedback, which is a value greater than or equal to 1 and less than or equal to the cipher block size (16 bytes for AES).

**unsigned int direction**

**0**

Use the decrypt function.

**1**

Use the encrypt function.

### Return codes

**0**
Success

For return codes indicating exceptions, see “Return codes” on page 138.

## ica_aes_cmac

### Purpose

Authenticate data or verify the authenticity of data with an AES key using the Block Cipher Based Message Authentication Code (CMAC) mode, as described in NIST Special Publication 800-38B. `ica_aes_cmac` can be used to authenticate or verify the authenticity of a complete message.

### Format

```
unsigned int ica_aes_cmac(const unsigned char *message,
  unsigned long message_length,
  unsigned char *mac,
  unsigned int mac_length,
  const unsigned char *key,
  unsigned int key_length,
  unsigned int direction);
```

### Required hardware support

KMAC-AES-128, KMAC-AES-192 or KMAC-AES-256

PCC-Compute-Last_block-CMAC-Using-AES-128, PCC-Compute-Last_block-CMAC-Using-AES-192, or PCC-Compute-Last_block-CMAC-Using-AES-256

### Parameters

**const unsigned char *message**
Pointer to a readable buffer of size greater than or equal to *message_length* bytes. This buffer contains a message to be authenticated, or of which the authenticity is to be verified.

**unsigned long message_length**
Length in bytes of the message to be authenticated or verified.

**unsigned char *mac**
Pointer to a buffer of size greater than or equal to *mac_length* bytes. If *direction* is equal to 1, the buffer must be writable and a message authentication code for the message in message of size *mac_length* bytes is written to this buffer. If direction is equal to 0, this buffer must be readable and contain a message authentication code to be verified against the message in *message*.

**unsigned int mac_length**
Length in bytes of the message authentication code *mac* in bytes, which is less than or equal to the cipher block size (16 bytes for AES). It is recommended to use values greater than or equal to 8.

**const unsigned char *key**
Pointer to a valid AES key.

**unsigned int key_length**
Length in bytes of the AES key. Supported sizes are 16, 24, and 32 for AES-128, AES-192, and AES-256 respectively. Therefore, you can use the definitions: `AES_KEY_LEN128`, `AES_KEY_LEN192`, and `AES_KEY_LEN256`.

**unsigned int direction**

**0**
Verify message authentication code.

**1**

Compute message authentication code for the message.

### Return codes

**0**

Success

**EFAULT**

If *direction* is equal to 0 and the verification of the message authentication code fails.

For return codes indicating exceptions, see "Return codes" on page 138.

## ica_aes_cmac_intermediate

### Purpose

Authenticate data or verify the authenticity of data with an AES key using the Block Cipher Based Message Authentication Code (CMAC) mode, as described in NIST Special Publication 800-38B. `ica_aes_cmac_intermediate` and `ica_aes_cmac_last` can be used when the message to be authenticated or to be verified using CMAC is supplied in multiple chunks. `ica_aes_cmac_intermediate` is used to process all but the last chunk. All message chunks to be processed by `ica_aes_cmac_intermediate` must have a size that is a multiple of the cipher block size (a multiple of 16 bytes for AES).

Note that `ica_aes_cmac_intermediate` has no direction argument. This function can be used during authentication and during authenticity verification.

### Format

```
unsigned int ica_aes_cmac_intermediate(const unsigned char *message,
  unsigned long message_length,
  const unsigned char *key,
  unsigned int key_length,
  unsigned char *iv);
```

### Required hardware support

KMAC-AES-128, KMAC-AES-192, or KMAC-AES-256

### Parameters

**const unsigned char *message**

Pointer to a readable buffer of size greater than or equal to *message_length* bytes. This buffer contains a non-final part of a message, to be authenticated or of which the authenticity is to be verified.

**unsigned long message_length**

Length in bytes of the message part in *message*. This value must be a multiple of the cipher block size.

**const unsigned char *key**

Pointer to a valid AES key.

**unsigned int key_length**

Length in bytes of the AES key. Supported sizes are 16, 24, and 32 for AES-128, AES-192, and AES-256 respectively. Therefore, you can use the definitions: AES_KEY_LEN128, AES_KEY_LEN192, and AES_KEY_LEN256.

**unsigned char *iv**

Pointer to a valid initialization vector of cipher block size number of bytes (16 bytes for AES). For the first message part, this parameter must be set to a string of zeros. For processing the *n*-th message part, this parameter must be the resulting *iv* value of the `ica_aes_cmac_intermediate` function applied to the (*n-1*)-th message part. This vector is overwritten during the function. The result value in *iv* can be used as the initialization vector for a chained call to `ica_aes_cmac_initermediate` or to `ica_aes_cmac_last` with the same key.

### Return codes

**0**
Success

For return codes indicating exceptions, see “Return codes” on page 138.

## ica_aes_cmac_last

### Purpose

Authenticate data or verify the authenticity of data with an AES key using the Block Cipher Based Message Authentication Code (CMAC) mode, as described in NIST Special Publication 800-38B. `ica_aes_cmac_last` can be used to authenticate or verify the authenticity of a complete message, or of the final part of a message for which all preceding parts were processed with `ica_aes_cmac_intermediate`.

### Format

```
unsigned int ica_aes_cmac_last(const unsigned char *message,
  unsigned long message_length,
  unsigned char *mac,
  unsigned int mac_length,
  const unsigned char *key,
  unsigned int key_length,
  unsigned char *iv,
  unsigned int direction);
```

### Required hardware support

KMAC-AES-128, KMAC-AES-192 or KMAC-AES-256

PCC-Compute-Last_block-CMAC-Using-AES-128, PCC-Compute-Last_block-CMAC-Using-AES-192, or PCC-Compute-Last_block-CMAC-Using-AES-256

### Parameters

**const unsigned char *message**
Pointer to a readable buffer of size greater than or equal to *message_length* bytes. This buffer contains a message or the final part of a message to be authenticated, or of which the authenticity is to be verified.

**unsigned long message_length**
Length in bytes of the message to be authenticated or verified.

**unsigned char *mac**
Pointer to a buffer of size greater than or equal to *mac_length* bytes. If *direction* is equal to 1, the buffer must be writable and a message authentication code for the message in *message* of size *mac_length* bytes is written to the buffer. If *direction* is equal to 0, the buffer must be readable and contain a message authentication code that is verified against the message in *message*.

**unsigned int mac_length**
Length in bytes of the message authentication code *mac* in bytes, which is less than or equal to the cipher block size (16 bytes for AES). It is recommended to use values greater than or equal to 8.

**const unsigned char *key**
Pointer to a valid AES key.

**unsigned int key_length**

Length in bytes of the AES key. Supported sizes are 16, 24, and 32 for AES-128, AES-192, and AES-256 respectively. Therefore, you can use the definitions: `AES_KEY_LEN128`, `AES_KEY_LEN192`, and `AES_KEY_LEN256`.

**unsigned char *iv**

Pointer to a valid initialization vector of cipher block size number of bytes. If *iv* is NULL, *message* is assumed to be the complete message to be processed. Otherwise, *message* is the final part of a composite message to be processed, and *iv* contains the output vector resulting from processing all previous parts with chained calls to `ica_aes_cmac_intermediate` (the value returned in *iv* of the `ica_aes_cmac_intermediate` call applied to the penultimate message part).

**unsigned int direction**

**0**

Verify message authentication code.

**1**

Compute message authentication code for the message.

### Return codes

**0**

Success

**EFAULT**

If *direction* is equal to 0 and the verification of the message authentication code fails.

For return codes indicating exceptions, see "Return codes" on page 138.

## ica_aes_ctr

### Purpose

Encrypt or decrypt data with an AES key using Counter (CTR) mode, as described in NIST Special Publication 800-38A Chapter 6.5. With the counter mode, each message block of cipher block size (16 bytes for AES) is combined with a counter value of the same size during encryption and decryption.

Starting with an initial counter value to be combined with the first message block, subsequent counter values to be combined with subsequent message blocks are derived from preceding counter values by an increment function. The increment function used in `ica_aes_ctr` is an arithmetic increment without carry on the *M* least significant bits in the counter where *M* is a parameter to `ica_aes_ctr`.

### Format

```
unsigned int ica_aes_ctr(const unsigned char *in_data,
  unsigned char *out_data,
  unsigned long data_length,
  const unsigned char *key,
  unsigned int key_length,
  unsigned char *ctr,
  unsigned int ctr_width,
  unsigned int direction);
```

### Required hardware support

KMCTR-AES-128, KMCTR-AES-192, or KMCTR-AES-256

### Parameters

**const unsigned char *in_data**

Pointer to a readable buffer that contains the message to be encrypted or decrypted. The size of the message in bytes is *data_length*. The size of this buffer must be at least as large as *data_length*.

**unsigned char *out_data**

Pointer to a writable buffer to contain the resulting encrypted or decrypted message. The size of this buffer in bytes must be at least as large as *data_length*.

**unsigned long data_length**

Length in bytes of the message to be encrypted or decrypted, which resides at the beginning of *in_data*.

**const unsigned char *key**

Pointer to a valid AES key.

**unsigned int key_length**

Length in bytes of the AES key. Supported sizes are 16, 24, and 32 for AES-128, AES-192, and AES-256 respectively. Therefore, you can use the definitions: `AES_KEY_LEN128`, `AES_KEY_LEN192`, and `AES_KEY_LEN256`.

**unsigned char *ctr**

Pointer to a readable and writable buffer of the same size as the cipher block in bytes. *ctr* contains an initialization value for a counter function, and it is replaced by a new value. That new value can be used as an initialization value for a counter function in a chained `ica_aes_ctr` call with the same key, if the *data_length* used in the preceding call is a multiple of the cipher block size.

**unsigned int ctr_width**

A number *M* between 8 and the cipher block size in bits. The value is used by the counter increment function, which increments a counter value by incrementing without carry the least significant *M* bits of the counter value. The value must be a multiple of 8 and smaller than 64. When in FIPS mode, an additional counter overflow check is performed, so that the given data length divided by 64 is not greater than $2^M$.

is not greater than $2^M$ multiplied by the cipher block size.

**unsigned int direction**

**0**

Use the decrypt function.

**1**

Use the encrypt function.

## Return codes

**0**

Success

For return codes indicating exceptions, see “Return codes” on page 138.

# ica_aes_ctrlist

## Purpose

Encrypt or decrypt data with an AES key using Counter (CTR) mode, as described in NIST Special Publication 800-38A ,Chapter 6.5. With the counter mode, each message block of the same size as the cipher block in bytes is combined with a counter value of the same size during encryption and decryption.

The `ica_aes_ctrlist` function assumes that a list *n* of precomputed counter values is provided, where *n* is the smallest integer that is less than or equal to the message size divided by the cipher block size. This function optimally uses IBM Z hardware support for non-standard counter functions.

## Format

```
unsigned int ica_aes_ctrlist(const unsigned char *in_data,
  unsigned char *out_data,
  unsigned long data_length,
  const unsigned char *key,
  unsigned int key_length,
  const unsigned char *ctrlist,
  unsigned int direction);
```

### Required hardware support

KMCTR-DEAKMCTR-AES-128, KMCTR-AES-192, or KMCTR-AES-256

### Parameters

**const unsigned char *in_data**
Pointer to a readable buffer that contains the message to be encrypted or decrypted. The size of the message in bytes is *data_length*. The size of this buffer must be at least as large as *data_length*.

**unsigned char *out_data**
Pointer to a writable buffer to contain the resulting encrypted or decrypted message. The size of this buffer in bytes must be at least as large as *data_length*.

**unsigned long data_length**
Length in bytes of the message to be encrypted or decrypted, which resides at the beginning of *in_data*.

Calls to `ica_aes_ctrlist` with the same key can be chained if:

- With the possible exception of the last call in the chain the *data_length* used is a multiple of the cipher block size.
- The *ctrlist* argument of each chained call contains a list of counters that follows the counters used in the preceding call.

**const unsigned char *key**
Pointer to a valid AES key.

**unsigned int key_length**
Length in bytes of the AES key. Supported sizes are 16, 24, and 32 for AES-128, AES-192, and AES-256 respectively. Therefore, you can use the definitions: AES_KEY_LEN128, AES_KEY_LEN192, and AES_KEY_LEN256.

**const unsigned char *ctrlist**
Pointer to a readable buffer that is both of a size greater than or equal to *data_length*, and a multiple of the cipher block size (16 bytes for AES). *ctrlist* should contain a list of precomputed counter values, each of the same size as the cipher block.

**unsigned int direction**

**0**
Use the decrypt function.

**1**
Use the encrypt function.

### Return codes

**0**
Success

For return codes indicating exceptions, see “Return codes” on page 138.

## ica_aes_ecb

### Purpose

Encrypt or decrypt data with an AES key using Electronic Code Book (ECB) mode, as described in NIST Special Publication 800-38A Chapter 6.1.

### Format

```
unsigned int ica_aes_ecb(const unsigned char *in_data,
  unsigned char *output,
  unsigned int data_length,
  const unsigned char *key,
  unsigned int key_length,
  unsigned int direction);
```

### Required hardware support

KM-AES-128, KM-AES-192, or KM-AES-256

### Parameters

**const unsigned char *in_data**
Pointer to a readable buffer that contains the message to be encrypted or decrypted. The size of the message in bytes is *data_length*. The size of this buffer must be at least as large as *data_length*.

**unsigned char *out_data**
Pointer to a writable buffer to contain the resulting encrypted or decrypted message. The size of this buffer in bytes must be at least as large as *data_length*.

**unsigned long data_length**
Length in bytes of the message to be encrypted or decrypted, which resides at the beginning of *in_data*. *data_length* must be a multiple of the cipher block size (a multiple of 16 for AES).

**const unsigned char *key**
Pointer to a valid AES key.

**unsigned int key_length**
Length in bytes of the AES key. Supported sizes are 16, 24, and 32 for AES-128, AES-192, and AES-256 respectively. Therefore, you can use the definitions: `AES_KEY_LEN128`, `AES_KEY_LEN192`, and `AES_KEY_LEN256`.

**unsigned int direction**

**0**
Use the decrypt function.

**1**
Use the encrypt function.

### Return codes

**0**
Success

For return codes indicating exceptions, see "Return codes" on page 138.

## ica_aes_gcm

### Purpose

Encrypt data and authenticate data or decrypt data and check authenticity of data with an AES key using the Galois/Counter Mode (GCM), as described in NIST Special Publication 800-38D. If no message needs to be encrypted or decrypted and only authentication or authentication checks are requested, then this method implements the GMAC mode.

This function is blocked when running in FIPS mode, because in this case the initialization vector (IV) must be created internally using an approved random source. Applications may use functions `ica_aes_gcm_initialize_fips()`, `ica_aes_gcm_intermediate()`, and `ica_aes_gcm_last()` instead.

## Format

```
unsigned int ica_aes_gcm(unsigned char *plaintext,
  unsigned long plaintext_length,
  unsigned char *ciphertext,
  const unsigned char *iv,
  unsigned int iv_length,
  const unsigned char *aad,
  unsigned long aad_length,
  unsigned char *tag,
  unsigned int tag_length,
  const unsigned char *key,
  unsigned int key_length,
  unsigned int direction);
```

## Required hardware support

KM-AES-128, KM-AES-192 or KM-AES-256
KIMD-GHASH
KMCTR-AES-128, KMCTR_AES-192 or KMCTR-AES-256

If available, KMA-GCM-AES-128, KMA-GCM-AES-192, and KMA-GCM-AES-256 are used transparently for better performance.

## Parameters

**unsigned char *plaintext**

Pointer to a buffer of size greater than or equal to *plaintext_length* bytes. If *direction* is equal to 1, the *plaintext* buffer must be readable and contain a payload message of size *plaintext_length* to be encrypted. If direction is equal to 0, the *plaintext* buffer must be writable and if the authentication verification succeeds, the decrypted message in the most significant *plaintext_length* bytes of *ciphertext* is written to the buffer. Otherwise, the contents of the buffer are undefined.

**unsigned long plaintext_length**

Length in bytes of the message to be encrypted or decrypted. This value can be 0 unless *aad_length* is equal to 0. The value must be greater than or equal to 0 and less than ($2^{36}$) - 32.

**unsigned char *ciphertext**

Pointer to a buffer of size greater than or equal to *plaintext_length* bytes. If *direction* is equal to 1, then this buffer must be writable and the encrypted message from *plaintext* is written to that buffer. If *direction* is equal to 0, then this buffer is readable and contains an encrypted message of length *plaintext_length*.

**const unsigned char *iv**

Pointer to a readable buffer of size greater than or equal to *iv_length* bytes, which contains an initialization vector of size *iv_length*.

**unsigned int iv_length**

Length in bytes of the initialization vector in *iv*. The value must be greater than 0 and less than $2^{61}$. A length of 12 is recommended.

**const unsigned char *aad**

Pointer to a readable buffer of size greater than or equal to *aad_length* bytes. The additional authenticated data in the most significant *aad_length* bytes is subject to the message authentication code computation, but is not encrypted.

**unsigned int aad_length**

Length in bytes of the additional authenticated data in *aad*. The value must be greater than or equal to 0 and less than $2^{61}$.

**unsigned char *tag**

Pointer to a buffer of size greater than or equal to *tag_length* bytes. If *direction* is equal to 1, this buffer must be writable, and a message authentication code for the additional authenticated data in *aad* and the plain text in *plaintext* of size *tag_length* bytes is written to this buffer. If *direction* is equal to 0, this buffer must be readable and contain a message authentication code to be verified against the additional authenticated data in *aad* and the decrypted cipher text from *ciphertext*.

**unsigned int tag_length**
Length in bytes of the message authentication code tag. Valid values are 4, 8, 12, 13, 14, 15, and 16.

**const unsigned char *key**
Pointer to a valid AES key.

**unsigned int key_length**
Length in bytes of the AES key. Supported sizes are 16, 24, and 32 for AES-128, AES-192, and AES-256 respectively. Therefore, you can use the definitions: `AES_KEY_LEN128`, `AES_KEY_LEN192`, and `AES_KEY_LEN256`.

**unsigned int direction**

**0**
Verify message authentication code and decrypt encrypted payload.

**1**
Encrypt payload and compute message authentication code for the additional authenticated data and the payload.

### Return codes

**0**
Success

**EFAULT**
If *direction* is equal to 0 and the verification of the message authentication code fails.

For return codes indicating exceptions, see “Return codes” on page 138.

## ica_aes_gcm_initialize

### Purpose

Start and initialize a new session of AES-GCM for stream cipher requests.

This function is blocked when running in FIPS mode, because in this case the initialization vector (IV) must be created internally using an approved random source. Applications may use function `ica_aes_gcm_initialize_fips()` instead.

### Format

```
unsigned int ica_aes_gcm_initialize(const unsigned char *iv,
  unsigned int iv_length,
  unsigned char *key,
  unsigned int key_length,
  unsigned char *icb,
  unsigned char *ucb,
  unsigned char *subkey,
  unsigned int direction);
```

### Required hardware support

KM-AES-128, KM-AES-192 or KM-AES-256
KIMD-GHASH
KMCTR-AES-128, KMCTR_AES-192 or KMCTR-AES-256

If available, KMA-GCM-AES-128, KMA-GCM-AES-192, and KMA-GCM-AES-256 are used transparently for better performance.

### Parameters

**unsigned char *iv**
Pointer to a readable buffer of size greater than or equal to **`iv_length`** bytes, that contains an initialization vector of size **`iv_length`**.

**unsigned int iv_length**
Length in bytes of the initialization vector in **`iv`**. It must be greater than 0 and less than $2^{61}$. A length of 12 is recommended.

**unsigned char *key**
Pointer to a valid AES key.

**unsigned int key_length**
Length in bytes of the AES key. Supported sizes are 16, 24, and 32 for AES-128, AES-192 and AES-256 respectively. Therefore, you can use the macros: `AES_KEY_LEN128`, `AES_KEY_LEN192`, and `AES_KEY_LEN256`.

**unsigned char *icb**
Pointer to the initial counter block, which is a writable buffer of size **`AES_BLOCK_SIZE`** (16 bytes). This buffer is filled by `ica_aes_gcm_initialize()` and used in `ica_aes_gcm_last()` for the final tag computation.

**unsigned char *ucb**
Pointer to the usage counter block, which is a writable buffer of size **`AES_BLOCK_SIZE`** (16 bytes). This buffer is filled by `ica_aes_gcm_initialize()` and updated (increased) during the intermediate update operations.

**unsigned char *subkey**
Pointer to the subkey block, which is a writable buffer (subkey block) of size **`AES_BLOCK_SIZE`** (16 bytes). This buffer is filled by `ica_aes_gcm_initialize()` and used in `ica_aes_gcm_intermediate()` and `ica_aes_gcm_last()`.

**unsigned int direction**

**0**
Verify message authentication code and decrypt encrypted payload.

**1**
Encrypt payload and compute message authentication code for the additional authenticated data and the payload.

### Return codes

**0**
Success

**EIO**
If the operation fails.

**EFAULT**
If **`direction`** equals 0 and the verification of the message authentication code fails.

For return codes indicating exceptions, see "Return codes" on page 138.

## ica_aes_gcm_initialize_fips

### Purpose

Start and initialize a new session of AES-GCM for stream cipher requests.

The `ica_aes_gcm_initialize_fips()` API creates the initialization vector internally using an approved random source and passes it back to the application in the **`iv`** output parameter. Therefore, the application must provide a writable buffer of sufficient length to receive the internal initialization vector. The minimum **`iv_length`** in FIPS mode is 12 bytes.

## Format

```
unsigned int ica_aes_gcm_initialize_fips(const unsigned char *iv,
  unsigned int iv_length,
  unsigned char *key,
  unsigned int key_length,
  unsigned char *icb,
  unsigned char *ucb,
  unsigned char *subkey,
  unsigned int direction);
```

## Required hardware support

KM-AES-128, KM-AES-192 or KM-AES-256
KIMD-GHASH
KMCTR-AES-128, KMCTR_AES-192 or KMCTR-AES-256

If available, KMA-GCM-AES-128, KMA-GCM-AES-192, and KMA-GCM-AES-256 are used transparently for better performance.

## Parameters

**unsigned char *iv**

Pointer to a readable buffer of size greater than or equal to **`iv_length`** bytes, that contains an initialization vector of size **`iv_length`**.

**unsigned int iv_length**

Length in bytes of the initialization vector in **`iv`**. It must be greater than 0 and less than $2^{61}$. A length of 12 is recommended.

**unsigned char *key**

Pointer to a valid AES key.

**unsigned int key_length**

Length in bytes of the AES key. Supported sizes are 16, 24, and 32 for AES-128, AES-192 and AES-256 respectively. Therefore, you can use the macros: AES_KEY_LEN128, AES_KEY_LEN192, and AES_KEY_LEN256.

**unsigned char *icb**

Pointer to the initial counter block, which is a writable buffer of size **`AES_BLOCK_SIZE`** (16 bytes). This buffer is filled by `ica_aes_gcm_initialize()` and used in `ica_aes_gcm_last()` for the final tag computation.

**unsigned char *ucb**

Pointer to the usage counter block, which is a writable buffer of size **`AES_BLOCK_SIZE`** (16 bytes). This buffer is filled by `ica_aes_gcm_initialize()` and updated (increased) during the intermediate update operations.

**unsigned char *subkey**

Pointer to the subkey block, which is a writable buffer (subkey block) of size **`AES_BLOCK_SIZE`** (16 bytes). This buffer is filled by `ica_aes_gcm_initialize()` and used in `ica_aes_gcm_intermediate()` and `ica_aes_gcm_last()`.

**unsigned int direction**

**0**

Verify message authentication code and decrypt encrypted payload.

**1**

Encrypt payload and compute message authentication code for the additional authenticated data and the payload.

### Return codes

**0**
Success

**EIO**
If the operation fails.

**EFAULT**
If **direction** equals 0 and the verification of the message authentication code fails.

For return codes indicating exceptions, see "Return codes" on page 138.

## ica_aes_gcm_intermediate

### Purpose

Authenticate data or verify the authenticity of data with an AES key using the Galois/Counter Mode (GCM), as described in NIST Special Publication 800-38D. `ica_aes_gcm_intermediate()` and `ica_aes_gcm_last()` can be used when the message to be authenticated or to be verified using GCM is supplied in multiple chunks. `ica_aes_gcm_intermediate()` is used to process all data chunks. Be aware that all chunks, with the possible exception of the last one, must be a multiple of **AES_BLOCK_SIZE** (16 bytes). The last data chunk might be any size. In any cases the `ica_aes_gcm_last()` must be called at the end to calculate the final authentication tag.

### Format

```
unsigned int ica_aes_gcm_intermediate(unsigned char *plaintext,
  unsigned long plaintext_length,
  unsigned char *ciphertext,
  unsigned char *ucb,
  unsigned char *aad,
  unsigned long aad_length,
  unsigned char *tag,
  unsigned int tag_length,
  unsigned char *key,
  unsigned int key_length,
  unsigned char *subkey,
  unsigned int direction);
```

### Required hardware support

KIMD-GHASH
KMCTR-AES-128, KMCTR_AES-192 or KMCTR-AES-256

If available, KMA-GCM-AES-128, KMA-GCM-AES-192, and KMA-GCM-AES-256 are used transparently for better performance.

### Parameters

**unsigned char *plaintext**
Pointer to a buffer of size greater than or equal to **plaintext_length** bytes.

If **direction** equals 1, the **plaintext** buffer must be readable and contain a payload message of size **plaintext_length** that is encrypted. If **direction** equals 0 the **plaintext** buffer must be writable.

If the authentication verification succeeds, the decrypted message in the most significant **plaintext_length** bytes of **ciphertext** is written to the buffer. Otherwise the contents of the buffer is undefined.

**unsigned long plaintext_length**

Length in bytes of the message to be encrypted or decrypted. It must be equal or greater than 0 and less than $2^{36}$-32. With the exception of the call followed by a call to `ica_aes_gcm_last()`, the value must be a multiple of **AES_BLOCK_SIZE**. Only in the call followed by `ica_aes_gm_last()`, the value does not have to be a multiple of **AES_BLOCK_SIZE**. Padding is done automatically.

**unsigned char *ciphertext**

Pointer to a buffer of a size which is a multiple of **AES_BLOCK_SIZE** and which is greater than or equal to **plaintext_length** bytes.

If **direction** equals 1, then the buffer must be writable and the encrypted message from **plaintext** is written to that buffer. If **direction** equals 0, then the buffer is readable and contains an encrypted message of a length which is equal to the least multiple of **AES_BLOCK_SIZE** that is greater than or equal to **plaintext_length**.

**unsigned char *ucb**

Pointer to the usage counter block, which is a writable buffer that is created during `ica_aes_gcm_initialize()` and is updated (increased) during the intermediate update operations. The length of this counter block is **AES_BLOCK_SIZE** (16 bytes). It is assumed that with the call to `ica_aes_gcm_intermediate()` the contents of the usage counter block was returned in the **ucb** parameter of a preceding call to `ica_aes_gcm_init()` or `ica_aes_gcm_intermediate()`.

**unsigned char *aad**

Pointer to a readable buffer of size greater than or equal to **aad_length** bytes. The additional authenticated data in the most significant **aad_length** bytes is subject to the authentication code computation, but is not encrypted.

**unsigned long aad_length**

Length in bytes of the additional authenticated data in **aad**. It must be equal to or greater than 0 and less than $2^{61}$, and the following constraints must apply:

- If the **aad_length** is not a multiple of **AES_BLOCK_SIZE** or 0, then in all subsequent calls to `ica_aes_gcm_intermediate()` that belong to the same AES GCM computation, the **aad_length** must be 0 which implies that only the last **aad** chunk can have a length that is not a multiple of **AES_BLOCK_SIZE**.
- If in a preceding call to `ica_aes_gcm_intermediate()` belonging to the same AES GCM computation, the **plaintext_length** was greater than 0, then **aad_length** must be 0, which implies that plaintext or ciphertext can only be supplied when all additional authenticated data is supplied.

**unsigned char *tag**

Contains the temporary hash/tag value. It is an input/output parameter and must be 16 byte long.

**unsigned int tag_length**

This parameter is currently not used.

**unsigned char *key**

Pointer to a valid AES key.

**unsigned int key_length**

Length in bytes of the AES key. Supported sizes are 16, 24, and 32 for AES-128, AES-192, and AES-256 respectively. Therefore, you can use the macros: AES_KEY_LEN128, AES_KEY_LEN192, and AES_KEY_LEN256.

**unsigned char *subkey**

Pointer to a writable buffer, generated in `ica_aes_gcm_initialize()` and used in `ica_aes_gcm_intermediate()` and `ica_aes_gcm_last()`. The length of this buffer is **AES_BLOCK_SIZE** (16 bytes).

**unsigned int direction**

**0**

Verify message authentication code and decrypt encrypted payload.

**1**
Encrypt payload and compute message authentication code for the additional authenticated data and the payload.

### Return codes

**0**
Success

**EIO**
If the operation fails.

**EFAULT**
If *direction* is equal to 0 and the verification of the message authentication code fails.

For return codes indicating exceptions, see "Return codes" on page 138.

## ica_aes_gcm_last

### Purpose

Authenticate data or verify the authenticity of data with an AES key using the Galois/Counter Mode (GCM), as described in NIST Special Publication 800-38D. `ica_aes_gcm_last()` must be used to authenticate or verify the authenticity of a message for which all preceding parts were processed with `ica_aes_gcm_intermediate()`.

### Format

```
unsigned int ica_aes_gcm_last(unsigned char *icb,
  unsigned long aad_length,
  unsigned long ciph_length,
  unsigned char *tag,
  unsigned char *final_tag,
  unsigned int final_tag_length,
  unsigned char *key,
  unsigned int key_length,
  unsigned char *subkey,
  unsigned int direction);
```

### Required hardware support

KIMD-GHASH

KMCTR-AES-128, KMCTR_AES-192 or KMCTR-AES-256

If available, KMA-GCM-AES-128, KMA-GCM-AES-192, and KMA-GCM-AES-256 are used transparently for better performance.

### Parameters

**unsigned char *icb**
Pointer to the initial counter block, which is a writable buffer that is created during `ica_aes_gcm_initialize()` and is used in `ica_aes_gcm_last()` for the final tag computation. The length of this counter block is **`AES_BLOCK_SIZE`** (16 bytes).

**unsigned long aad_length**
Overall length of authentication data, cumulated over all intermediate operations.

**unsigned long ciph_length**
Length in bytes of the overall ciphertext, cumulated over all intermediate operations.

**unsigned char *tag**
Contains the temporary hash/tag value computed during preceding `ica_aes_gcm_initialize()` and `ica_aes_gcm_intermediate()` calls.

**unsigned char *final_tag**

Pointer to a readable buffer of size greater than or equal to **`final_tag_length`** bytes. If **`direction`** is 1, the buffer is not used. If **`direction`** is 0, this message authentication code (tag) is verified with the message authentication code computed over the intermediate update operations.

**unsigned int final_tag_length**

Length in bytes of the final message authentication code (tag). Valid values are 4, 8, 12, 13, 14, 15, and 16.

**unsigned char *key**

Pointer to a valid AES key.

**unsigned int key_length**

Length in bytes of the AES key. Supported sizes are 16, 24, and 32 for AES-128, AES-192 and AES-256 respectively. Therefore, you can use the macros: `AES_KEY_LEN128`, `AES_KEY_LEN192`, and `AES_KEY_LEN256`.

**unsigned char *subkey**

Pointer to a writable buffer generated in `ica_aes_gcm_initialize()` and used in `ica_aes_gcm_intermediate()` and `ica_aes_gcm_last()`. The length of this subkey block is **`AES_BLOCK_SIZE`** (16 bytes).

**unsigned int direction**

**0**

Verify message authentication code and decrypt encrypted payload.

**1**

Encrypt payload and compute message authentication code for the additional authenticated data and the payload.

### Return codes

**0**

Success

**EIO**

If the operation fails.

**EFAULT**

If *direction* is equal to 0 and the verification of the message authentication code fails.

For return codes indicating exceptions, see “Return codes” on page 138.

## ica_aes_gcm_kma_ctx_new

### Purpose

Allocate a GCM context for all other KMA-related GCM functions and return a pointer to this context. The context buffer is used by all other `ica_aes_gcm_kma` functions as a working area and must not be changed by the application. It must be freed by `ica_aes_gcm_kma_ctx_free()` when no longer needed.

### Format

```
kma_ctx* ica_aes_gcm_kma_ctx_new();
```

### Parameters

None.

### Return codes

**NULL**
Returns a NULL pointer if no memory could be allocated. Returns a pointer to a GCM context if successful.

## ica_aes_gcm_kma_ctx_free

### Purpose

Deallocates a previously allocated GCM context.

### Format

```
void ica_aes_gcm_kma_ctx_free(kma_ctx *ctx);
```

### Parameters

**kma_ctx *ctx**
Pointer to a previously allocated GCM context that is to be deallocated.

### Return codes

None.

## ica_aes_gcm_kma_init

### Purpose

Initialize the GCM context as returned from `ica_aes_gcm_kma_ctx_new()`**`direction`** either for encryption (**`direction`** = 1) or decryption ( = 0).

This function is blocked when running in FIPS mode, because in this case the initialization vector (IV) must be created internally using an approved random source. Applications may use function `ica_aes_gcm_kma_init_fips()` instead.

### Format

```
int ica_aes_gcm_kma_init(unsigned int direction,
  const unsigned char *iv,
  unsigned int iv_length,
  const unsigned char *key,
  unsigned int key_length,
  kma_ctx *ctx);
```

### Required hardware support

KIMD-GHASH
KM-AES-128, KM-AES-192, or KM-AES-256

If available, KMA-GCM-AES-128, KMA-GCM-AES-192, and KMA-GCM-AES-256 are used transparently for better performance.

### Parameters

**unsigned int direction**

**0**
Use the decrypt function.

**1**
Use the encrypt function.

**const unsigned char *iv**
Pointer to a readable buffer that contains an initialization vector. The buffer size, in bytes, can be equal to the vector length (**iv_length**) or greater.

**unsigned int iv_length**
Length, in bytes, of the initialization vector in buffer **iv**. The value must be greater than 0 and less than $2^{61}$. A length of 12 is recommended.

**const unsigned char *key**
Pointer to a valid AES key.

**unsigned int key_length**
Length of the AES key in bytes. Supported sizes are 16, 24, and 32 for AES-128, AES-192 and AES-256 respectively. Therefore, you can use the macros AES_KEY_LEN128, AES_KEY_LEN192, and AES_KEY_LEN256.

**kma_ctx *ctx**
Pointer to a previously allocated GCM context. This buffer is internally used as a working area by all other ica_aes_gcm_kma API functions and must not be changed by the application. The **ctx** context must be established by calling ica_aes_gcm_ctx_new() before any call to any other ica_aes_gcm_kma function, and must be freed by calling ica_aes_gcm_ctx_free() after the last call to any ica_aes_gcm_kma function.

### Return codes

**0**
Success

**EIO**
If the operation fails.

For return codes indicating exceptions, see "Return codes" on page 138.

## ica_aes_gcm_kma_init_fips

### Purpose

Initialize the GCM context as returned from ica_aes_gcm_kma_ctx_new(). In contrast to the ica_aes_gcm_kma_init() function, this API is intended to be used in FIPS mode and has no initialization vector (IV) parameter, as external IVs are not allowed in FIPS mode. An internal FIPS-compliant initialization vector is created and can be obtained from the context using the ica_aes_gcm_kma_get_iv() function (see "ica_aes_gcm_kma_get_iv" on page 94). The minimum length of the IV in FIPS mode is 12 bytes (parameter **iv_length**).

### Format

```
int ica_aes_gcm_kma_init_fips(unsigned int direction,
  unsigned int iv_length,
  const unsigned char *key,
  unsigned int key_length,
  kma_ctx *ctx);
```

### Required hardware support

KIMD-GHASH
KM-AES-128, KM-AES-192, or KM-AES-256

If available, KMA-GCM-AES-128, KMA-GCM-AES-192, and KMA-GCM-AES-256 are used transparently for better performance.

## Parameters

**unsigned int direction**

**0**
Use the decrypt function.

**1**
Use the encrypt function.

**unsigned int iv_length**
Length, in bytes, of the initialization vector in buffer **iv**. The value must be greater than 0 and less than $2^{61}$. A length of 12 bytes is recommended and is the minimum length in FIPS mode.

**const unsigned char *key**
Pointer to a valid AES key.

**unsigned int key_length**
Length of the AES key in bytes. Supported sizes are 16, 24, and 32 for AES-128, AES-192 and AES-256 respectively. Therefore, you can use the macros AES_KEY_LEN128, AES_KEY_LEN192, and AES_KEY_LEN256.

**kma_ctx *ctx**
Pointer to a previously allocated GCM context. This buffer is internally used as a working area by all other `ica_aes_gcm_kma` API functions and must not be changed by the application. The **`ctx`** context must be established by calling `ica_aes_gcm_ctx_new()` before any call to any other `ica_aes_gcm_kma` function, and must be freed by calling `ica_aes_gcm_ctx_free()` after the last call to any `ica_aes_gcm_kma` function.

## Return codes

**0**
Success

**EIO**
If the operation fails.

For return codes indicating exceptions, see "Return codes" on page 138.

# ica_aes_gcm_kma_get_iv

## Purpose

Obtain the initialization vector (IV) from the given context. This function is mainly intended to allow applications to query an internally created IV when running in FIPS mode. When encrypting, FIPS requires the internal creation of the IV using an approved random source. The internal IV can then be queried for use at decryption.

## Format

```
int ica_aes_gcm_kma_get_iv(const kma_ctx* ctx,
  unsigned char *iv,
  unsigned int *iv_length);
```

## Required hardware support

None.

## Parameters

**const kma_ctx* ctx**
Pointer to a GCM context.

**unsigned char *iv**

A writable buffer large enough to receive the initialization vector from the given context (**ctx**). Specifying NULL queries the size of the internal initialization vector. The size is then returned in parameter ***iv_length**.

**unsigned int *iv_length**

A pointer to an unsigned integer buffer indicating the size of the application-provided buffer to receive the internal IV from the GCM context (**ctx**).

### Return codes

**0**

Success

**EINVAL**

If the GCM context (**ctx**) is NULL.

**ENOMEM**

If the IV length (***iv_length**) is too small to receive the internal IV.

For return codes indicating exceptions, see "Return codes" on page 138.

## ica_aes_gcm_kma_update

### Purpose

Perform encryption of plain text or decryption of cipher text with authentication, depending on the direction specified in `ica_aes_gcm_kma_init()`. It also processes optional additional authenticated data (parameter **aad**). It can be used either for a single call when all **aad** data and the complete plain text or cipher text is known. Or it can also be used for processing chunks of **aad** data, and chunks of plain text or cipher text.

Each chunk of plain text or cipher text from parameter **in_data** or each chunk of data from **aad** must be a multiple of the AES block size (16 bytes), except of the last one.

If any chunk from **aad** or **in_data** is not a multiple of 16, the application must indicate this either in parameter **end_of_aad** or **end_of_data**. When **end_of_aad** was indicated, no more additional authenticated data can be provided. When **end_of_data** was indicated, no more message data can be provided. The process ends when both, **end_of_aad** and **end_of_data** are set.

### Format

```
int ica_aes_gcm_kma_update(const unsigned char *in_data,
  unsigned char *out_data,
  unsigned long data_length,
  const unsigned char *aad,
  unsigned long aad_length,
  unsigned int end_of_aad,
  unsigned int end_of_data,
  const kma_ctx *ctx)
```

### Required hardware support

KIMD-GHASH
KM-AES-128, KM-AES-192, or KM-AES-256

If available, KMA-GCM-AES-128, KMA-GCM-AES-192, and KMA-GCM-AES-256 are used transparently for better performance.

## Parameters

**const unsigned char *in_data**

Pointer to a readable buffer of size greater than or equal to **`data_length`** bytes. If **`direction`** = 1, parameter **`in_data`** must contain a payload message of size **`data_length`** that is encrypted and authenticated. If **`direction`** = 0, parameter **`in_data`** must contain an encrypted message that is decrypted and verified.

**unsigned char *out_data**

Pointer to a writable buffer of size **`data_length`** bytes or greater. If **`direction`** = 1, then the encrypted message from parameter **`in_data`** is written to that buffer. If **`direction`** = 0, then the decrypted message from the **`in_data`** buffer is written to that buffer. The pointer to **`out_data`** may point to the same buffer as for **`in_data`**, or a part of it, if you want to encrypt/decrypt in place.

**unsigned long data_length**

Length, in bytes, of the message to be encrypted or decrypted. The value must be equal or greater than 0 and less than ($2^{36}$) - 32.

**const unsigned char *aad**

Pointer to a readable buffer of size **`aad_length`** bytes or greater. The additional authenticated data in the most significant **`aad_length`** bytes is subject to the authentication code computation but is not encrypted.

**unsigned long aad_length**

Length, in bytes, of the additional authenticated data in parameter **aad**. It must be 0 or greater, and less than $2^{61}$.

**unsigned int end_of_aad**

Can be either 0 or 1:

**0**

The application indicates that the current content of **aad** is not the last chunk of additional authenticated data. In this case, the value of **`aad_length`** must be a multiple of the AES block size (16 bytes).

**1**

The application indicates that the current content of **aad** is a single chunk or the last chunk. Or the application indicates that the last **aad** chunk has been provided in an earlier call to a `ica_aes_gcm_kma` function. In this case, parameter **`aad_length`** can have any non-negative value.

When both, **`end_of_aad`** and **`end_of_data`** are specified, the process ends.

**unsigned int end_of_data**

Can be either 0 or 1:

**0**

The application indicates that the current content of **`in_data`** is not the last chunk. In this case, the value of parameter **`data_length`** must be a multiple of the AES block size (16 bytes).

**1**

The application indicates that the current content of **`in_data`** is a single chunk or the last chunk. In this case, **`aad_length`** can have any non-negative value.

When both, **`end_of_aad`** and **`end_of_data`** are specified, the process ends.

**const kma_ctx *ctx**

Pointer to a previously initialized GCM context.

The input GCM context must be the resulting context of a preceding `ica_aes_gcm_kma_init` or `ica_aes_gcm_kma_update` function call. The resulting context can be used as the input to a subsequent `ica_aes_gcm_kma_update`, `ica_aes_gcm_kma_get_tag` or `ica_aes_gcm_kma_verify_tag` call.

### Return codes

**0**
Success

**EIO**
If the operation fails.

For return codes indicating exceptions, see "Return codes" on page 138.

## ica_aes_gcm_kma_get_tag

### Purpose

Returns the calculated authentication tag after an encryption process.

### Format

```
int ica_aes_gcm_kma_get_tag(unsigned char *tag,
  unsigned int tag_length,
  const kma_ctx *ctx);
```

### Required hardware support

**z13 or earlier:**
KM-AES-128, KM-AES-192, or KM-AES-256

**z14:**
None.

If available, KMA-GCM-AES-128, KMA-GCM-AES-192, and KMA-GCM-AES-256 are used transparently for better performance.

### Parameters

**unsigned char *tag**
Pointer to a writable buffer to return the calculated authentication tag.

**unsigned int tag_length**
Length in bytes of the message authentication code tag. Valid tag lengths are 4, 8, 12, 13, 14, 15, and 16.

**const kma_ctx *ctx**
Pointer to the GCM context.

This context is the result of the of an `ica_aes_gcm_kma_update` call where the parameters **`end_of_aad`** and **`end_of_data`** where set to 1.

### Return codes

**0**
Success

**EFAULT**
If parameter **`direction`** of the **`ica_aes_gcm_kma_init()`** function is 0 (indicating a decryption function).

For return codes indicating exceptions, see "Return codes" on page 138.

# ica_aes_gcm_kma_verify_tag

## Purpose

Verifies if the calculated authentication tag is identical to the known authentication tag specified in parameter **`known_tag`** after a decryption process.

## Format

```
int ica_aes_gcm_kma_verify_tag(const unsigned char* known_tag,
  unsigned int tag_length, kma_ctx* ctx)
```

## Required hardware support

**z13 or earlier:**

KIMD-GHASH<br>
KM-AES-128, KM-AES-192, or KM-AES-256

**z14:**
None.

If available, KMA-GCM-AES-128, KMA-GCM-AES-192, and KMA-GCM-AES-256 are used transparently for better performance.

## Parameters

**const unsigned char* known_tag**
Pointer to a readable buffer containing a known authentication tag.

**unsigned int tag_length**
Length in bytes of the message authentication code tag. Valid tag lengths are 4, 8, 12, 13, 14, 15, and 16.

**kma_ctx* ctx**
Pointer to a GCM context.

This context is the result of the of an `ica_aes_gcm_kma_update` call where the parameters **`end_of_aad`** and **`end_of_data`** where set to 1.

## Return codes

**0**
Success

**EINVAL**
If at least one invalid parameter is given or **`direction`** is 1.

**EFAULT**
If the verification of the message authentication code fails.

For return codes indicating exceptions, see "Return codes" on page 138.

# ica_aes_ofb

## Purpose

Encrypt or decrypt data with an AES key using Output Feedback (OFB) mode, as described in NIST Special Publication 800-38A Chapter 6.4.

### Format

```
unsigned int ica_aes_ofb(const unsigned char *in_data,
  unsigned char *out_data,
  unsigned long data_length,
  const unsigned char *key,
  unsigned int key_length,
  unsigned char *iv,
  unsigned int direction);
```

### Required hardware support

KMO-AES-128, KMO-AES-192, or KMO-AES-256

### Parameters

**const unsigned char *in_data**

Pointer to a readable buffer that contains the message to be encrypted or decrypted. The size of the message in bytes is *data_length*. The size of this buffer must be at least as large as *data_length*.

**unsigned char *out_data**

Pointer to a writable buffer that to contain the resulting encrypted or decrypted message. The size of this buffer in bytes must be at least as large as *data_length*.

**unsigned long data_length**

Length in bytes of the message to be encrypted or decrypted, which resides at the beginning of *in_data*.

**const unsigned char *key**

Pointer to a valid AES key.

**unsigned int key_length**

Length in bytes of the AES key. Supported sizes are 16, 24, and 32 for AES-128, AES-192, and AES-256 respectively. Therefore, you can use the definitions: `AES_KEY_LEN128`, `AES_KEY_LEN192`, and `AES_KEY_LEN256`.

**unsigned char *iv**

Pointer to a valid initialization vector of the same size as the cipher block, in bytes (16 bytes for AES). This vector is overwritten during the function. If *data_length* is a multiple of the cipher block size (16 bytes for AES), the result value in *iv* can be used as the initialization vector for a chained `ica_aes_ofb` call with the same key.

**unsigned int direction**

**0**

Use the decrypt function.

**1**

Use the encrypt function.

### Return codes

**0**

Success

For return codes indicating exceptions, see “Return codes” on page 138.

## ica_aes_xts

### Purpose

Encrypt or decrypt data with an AES key using the XEX Tweakable Block Cipher with Ciphertext Stealing (XTS) mode, as described in NIST Special Publication 800-38E and IEEE standard 1619-2007. This function supports single-part operation only.

## Format

```
unsigned int ica_aes_xts(const unsigned char *in_data,
  unsigned char *out_data,
  unsigned long data_length,
  const unsigned char *key1,
  const unsigned char *key2,
  unsigned int key_length,
  unsigned char *tweak,
  unsigned int direction);
```

## Required hardware support

KM-XTS-AES-128, or KM-XTS-AES-256

PCC-Compute-XTS-Parameter-Using-AES-128, or PCC-Compute-XTS-Parameter-Using-AES-256

## Parameters

**const unsigned char *in_data**

Pointer to a readable buffer that contains the message to be encrypted or decrypted. The size of the message in bytes is **data_length**. The size of this buffer must be at least as large as **data_length**.

**unsigned char *out_data**

Pointer to a writable buffer to contain the resulting encrypted or decrypted message. The size of this buffer in bytes must be at least as large as **data_length**.

**unsigned long data_length**

Length in bytes of the message to be encrypted or decrypted, which resides at the beginning of **in_data**. The minimal **data_length** must be at least 16 bytes (16, 17, 18 ...) and needs not be a multiple of 16 (which is the AES cipher block size).

**const unsigned char *key1**

Pointer to a buffer containing a valid AES key. **key1** is used for the actual encryption of the message buffer, combined with some vector computed from the **tweak** value (Key1 in IEEE Std 1619-2007).

**const unsigned char *key2**

Pointer to a buffer containing a valid AES key. **key2** is used to encrypt the tweak (Key2 in IEEE Std 1619-2007).

**unsigned int key_length**

The length in bytes of the AES key. XTS-supported AES key sizes are 16 and 32, for AES-128 and AES-256 respectively. Therefore, you can use:

2 * AES_KEY_LEN128 and 2 * AES_KEY_LEN256.

**unsigned char *tweak**

Pointer to a valid 16-byte tweak value (as in IEEE standard 1619-2007). This tweak is overwritten during the function. If **data_length** is a multiple of the cipher block size (a multiple of 16 for AES), the result value in **tweak** can be used as the **tweak** value for a chained `ica_aes_xts` call with the same key pair.

**unsigned int direction**

Can be 0 or 1:

**0**

Use the decrypt function.

**1**

Use the encrypt function.

## Return codes

**0**

Success

For return codes indicating exceptions, see “Return codes” on page 138.

# ica_aes_xts_ex

## Purpose

Encrypt or decrypt data with an AES key using the XEX Tweakable Block Cipher with Ciphertext Stealing (XTS) mode, as described in NIST Special Publication 800-38E and IEEE standard 1619-2007. In contrast to `ica_aes_xts()`, the `ica_aes_xts()` API allows to encrypt multiple data parts of an input message by repeatedly calling the function for intermediate data parts and the final data part.

## Format

```
unsigned int ica_aes_xts_ex(const unsigned char *in_data,
  unsigned char *out_data,
  unsigned long data_length,
  const unsigned char *key1,
  const unsigned char *key2,
  unsigned int key_length,
  unsigned char *tweak,
  unsigned char *iv,
  unsigned int direction);
```

## Required hardware support

KM-XTS-AES-128, or KM-XTS-AES-256

PCC-Compute-XTS-Parameter-Using-AES-128, or PCC-Compute-XTS-Parameter-Using-AES-256

## Parameters

**const unsigned char *in_data**

Pointer to a readable buffer that contains the message to be encrypted or decrypted. The size of the message in bytes is **`data_length`**. The size of this buffer must be at least as large as **`data_length`**.

**unsigned char *out_data**

Pointer to a writable buffer to contain the resulting encrypted or decrypted message. The size of this buffer in bytes must be at least as large as **`data_length`**.

**unsigned long data_length**

Length in bytes of the message part to be encrypted or decrypted, which resides at the beginning of **`in_data`**. For multi-part operations, **`data_length`** for the first and intermediate message parts must be a multiple of the AES cipher block size of 16 bytes, (16, 32, 48, ... and so on). Any message part, whose **`data_length`** is longer than 16 bytes, but not a multiple of 16, is recognized as the final message part. Further calls of this function after a final message part has been processed, leads to unexpected results. If the **`data_length`** of the last message part is a multiple of 16 bytes, no special final block handling is required.

**const unsigned char *key1**

Pointer to a buffer containing a valid AES key. **`key1`** is used for the actual encryption of the message buffer, combined with some vector computed from the **`tweak`** value (Key1 in IEEE Std 1619-2007).

**const unsigned char *key2**

Pointer to a buffer containing a valid AES key. **`key2`** is used to encrypt the tweak (Key2 in IEEE Std 1619-2007).

**unsigned int key_length**

The length in bytes of the AES key. XTS-supported AES key sizes are 16 and 32, for AES-128 and AES-256 respectively.

**unsigned char *tweak**

Pointer to a valid 16-byte tweak value (as in IEEE standard 1619-2007). For multi-part operations the tweak must only be specified for the initial part. For subsequent parts, the tweak parameter must be NULL.

**unsigned char *iv**

Pointer to the initialization vector to be used for multi-part operations. If the tweak parameter is NULL, then the operation uses the initialization vector specified with this parameter. On return, the initialization vector is updated with the output vector that can be used as initialization vector for the next part. For single part operations, this parameter can be NULL.

**unsigned int direction**

Can be 0 or 1:

**0**

Use the decrypt function.

**1**

Use the encrypt function.

## Return codes

**0**

Success

**EINVAL**

If at least one invalid parameter is given.

**EIO**

If the operation fails.

**EPERM**

If required hardware support is not available.

For return codes indicating exceptions, see "Return codes" on page 138.

# TDES/3DES functions

Use the provided TDES/3DES functions for data encryption in various operation modes.

These functions are declared in: `include/ica_api.h`.

These functions perform encryption and decryption or computation and verification of message authentication codes using a triple-DES (3DES, TDES or TDEA) key. A 3DES key consists of a concatenation of three DES keys, each of which has a size of 8 bytes. Note that each byte of a DES key contains one parity bit, such that each 64-bit DES key contains only 56 security-relevant bits. The cipher block size for 3DES is 8 bytes.

3DES is known in two variants: a two key variant and a three key variant. This library implements only the three key variant. The two key variant can be derived from functions for the three key variant by using the same key as the first and third key.

To securely apply 3DES encryption to messages that are longer than the cipher block size, modes of operation can be used to chain multiple encryption, decryption, or authentication operations. Most modes of operation require an initialization vector as additional input. As long as the messages are encrypted or decrypted using such a mode of operation and have a size that is a multiple of a particular block size (mostly the cipher block size), the functions encrypting or decryption according to that mode of operation also compute an output vector that can be used as the initialization vector of a chained encryption or decryption operation in the same mode with the same block size and the same key.

Note that when decrypting a cipher text, the mode of operation, the key, the initialization vector (if applicable), and for `ica_3des_cfb` the *lcfb* value used for the decryption function must match the corresponding settings of the encryption function that was used to transform the plain text into the cipher text.

### Use of TDES/3DES functions in FIPS mode

According to the NIST guidelines, all functions described in this topic are deprecated since 2019 and will be prohibited for use by US government employees and personnel after 2023. Starting with libica version 4.1, all TDES/3DES functions can no longer be used when running in FIPS mode (FIPS 140-2 or later).

## ica_3des_cbc

### Purpose

Encrypt or decrypt data with an 3DES key using Cipher Block Chaining (CBC) mode, as described in NIST Special Publication 800-38A Chapter 6.2.

### Format

```
unsigned int ica_3des_cbc(const unsigned char *in_data,
  unsigned char *out_data,
  unsigned long data_length,
  const unsigned char *key,
  unsigned char *iv,
  unsigned int direction);
```

### Required hardware support

KMC-TDEA-192

### Parameters

**const unsigned char *in_data**

Pointer to a readable buffer that contains the message to be encrypted or decrypted. The size of the message in bytes is *data_length*. The size of this buffer must be at least as large as *data_length*.

**unsigned char *out_data**

Pointer to a writable buffer to contain the resulting encrypted or decrypted message. The size of this buffer in bytes must be at least as large as *data_length*.

**unsigned long data_length**

Length in bytes of the message to be encrypted or decrypted, which resides at the beginning of *in_data*. *data_length* must be a multiple of the cipher block size (8 bytes for 3DES).

**const unsigned char *key**

Pointer to a valid 3DES key of 24 bytes in length.

**unsigned char *iv**

Pointer to a valid initialization vector of cipher block size number of bytes. This vector is overwritten during the function. The result value in *iv* can be used as the initialization vector for a chained `ica_3des_cbc` or `ica_3des_cbc_cs` call with the same key.

**unsigned int direction**

**0**

Use the decrypt function.

**1**

Use the encrypt function.

### Return codes

**0**

Success

For return codes indicating exceptions, see "Return codes" on page 138.

# ica_3des_cbc_cs

## Purpose

Encrypt or decrypt data with a 3DES key using Cipher Block Chaining with Ciphertext Stealing (CBC-CS) mode, as described in NIST Special Publication 800-38A Chapter 6.2 and the Addendum to NIST Special Publication 800-38A on *Recommendation for Block Cipher Modes of Operation: Three Variants of Ciphertext Stealing for CBC Mode*.

`ica_3des_cbc_cs` can be used to encrypt or decrypt the last chunk of a message consisting of multiple chunks, where all chunks except the last one are encrypted or decrypted by chained calls to `ica_3des_cbc`. To do this, the resulting *iv* of the last call to `ica_3des_cbc` is fed into the *iv* of the `ica_3des_cbc_cs` call, provided that the chunk is greater than the cipher block size (8 bytes for 3DES).

## Format

```
unsigned int ica_3des_cbc_cs(const unsigned char *in_data,
  unsigned char *out_data,
  unsigned long data_length,
  const unsigned char *key,
  unsigned char *iv,
  unsigned int direction,
  unsigned int variant);
```

## Required hardware support

KMC-TDEA-192

## Parameters

**const unsigned char *in_data**

Pointer to a readable buffer that contains the message to be encrypted or decrypted. The size of the message in bytes is *data_length*. The size of this buffer must be at least as large as *data_length*.

**unsigned char *out_data**

Pointer to a writable buffer to contain the resulting encrypted or decrypted message. The size of this buffer in bytes must be at least as large as *data_length*.

**unsigned long data_length**

Length in bytes of the message to be encrypted or decrypted, which resides at the beginning of *in_data*. *data_length* must be greater than or equal to the cipher block size (8 bytes for 3DES).

**const unsigned char *key**

Pointer to a valid 3DES key of 24 bytes in length.

**unsigned char *iv**

Pointer to a valid initialization vector of the same size as the cipher block in bytes. This vector is overwritten during the function. For *variant* equal to 1 or *variant* equal to 2, the result value in *iv* can be used as the initialization vector for a chained `ica_3des_cbc` or `ica_3des_cbc_cs` call with the same key, if *data_length* is a multiple of the cipher block size.

**unsigned int direction**

**0**

Use the decrypt function.

**1**

Use the encrypt function.

**unsigned int variant**

**1**

Use variant CBC-CS1 of the Addendum to NIST Special Publication 800-38A to encrypt or decrypt the message: always keep last two blocks in order.

**2**

Use variant CBC-CS2 of the Addendum to NIST Special Publication 800-38A to encrypt or decrypt the message: switch order of the last two blocks if *data_length* is not a multiple of the cipher block size (a multiple of 8 bytes for 3DES).

**3**

Use variant CBC-CS3 of the Addendum to NIST Special Publication 800-38A to encrypt or decrypt the message: always switch order of the last two blocks.

### Return codes

**0**

Success

For return codes indicating exceptions, see "Return codes" on page 138.

## ica_3des_cfb

### Purpose

Encrypt or decrypt data with a 3DES key using Cipher Feedback (CFB) mode, as described in NIST Special Publication 800-38A Chapter 6.3.

### Format

```
unsigned int ica_3des_cfb(const unsigned char *in_data,
  unsigned char *out_data,
  unsigned long data_length,
  const unsigned char *key,
  unsigned char *iv,
  unsigned int lcfb,
  unsigned int direction);
```

### Required hardware support

KMF-TDEA-192

### Parameters

**const unsigned char *in_data**

Pointer to a readable buffer that contains the message to be encrypted or decrypted. The size of the message in bytes is *data_length*. The size of this buffer must be at least as large as *data_length*.

**unsigned char *out_data**

Pointer to a writable buffer to contain the resulting encrypted or decrypted message. The size of this buffer in bytes must be at least as large as *data_length*.

**unsigned long data_length**

Length in bytes of the message to be encrypted or decrypted, which resides at the beginning of *in_data*.

**const unsigned char *key**

Pointer to a valid 3DES key of 24 bytes in length.

**unsigned char *iv**

Pointer to a valid initialization vector of cipher block size number of bytes (8 bytes for 3DES). This vector is overwritten during the function. The result value in *iv* can be used as the initialization vector for a chained `ica_3des_cfb` call with the same key, if the *data_length* in the preceding call is a multiple of *lcfb*.

**unsigned int lcfb**

Length in bytes of the cipher feedback, which is a value greater than or equal to 1 and less than or equal to the cipher block size (8 bytes for 3DES).

**unsigned int direction**

**0**

Use the decrypt function.

**1**

Use the encrypt function.

### Return codes

**0**

Success

For return codes indicating exceptions, see "Return codes" on page 138.

## ica_3des_cmac

### Purpose

Authenticate data or verify the authenticity of data with an 3DES key using the Block Cipher Based Message Authentication Code (CMAC) mode, as described in NIST Special Publication 800-38B. `ica_3des_cmac` can be used to authenticate or verify the authenticity of a complete message.

### Format

```
unsigned int ica_3des_cmac(const unsigned char *message,
  unsigned long message_length,
  unsigned char *mac,
  unsigned int mac_length,
  const unsigned char *key,
  unsigned int direction);
```

### Required hardware support

KMAC-TDEA-192

PCC-Compute-Last_block-CMAC-Using-TDEA-192

### Parameters

**const unsigned char *message**

Pointer to a readable buffer of size greater than or equal to *message_length* bytes. This buffer contains a message to be authenticated, or of which the authenticity is to be verified.

**unsigned long message_length**

Length in bytes of the message to be authenticated or verified.

**unsigned char *mac**

Pointer to a buffer of size greater than or equal to *mac_length* bytes. If *direction* is equal to 1, the buffer must be writable and a message authentication code for the message in *message* of size *mac_length* bytes is written to the buffer. If *direction* is equal to 0, the buffer must be readable and contain a message authentication code to be verified against the message in *message*.

**unsigned int mac_length**

Length in bytes of the message authentication code *mac*, which is less than or equal to the cipher block size (8 bytes for 3DES). It is recommended to use a *mac_length* of 8.

**const unsigned char *key**

Pointer to a valid 3DES key of 24 bytes in length.

**unsigned int direction**

**0**
Verify message authentication code.

**1**
Compute message authentication code for the message.

### Return codes

**0**
Success

**EFAULT**
If *direction* is equal to 0 and the verification of the message authentication code fails.

For return codes indicating exceptions, see "Return codes" on page 138.

## ica_3des_cmac_intermediate

### Purpose

Authenticate data or verify the authenticity of data with an 3DES key using the Block Cipher Based Message Authentication Code (CMAC) mode, as described in NIST Special Publication 800-38B. `ica_3des_cmac_intermediate` and `ica_3des_cmac_last` can be used when the message to be authenticated or to be verified using CMAC is supplied in multiple chunks. `ica_3des_cmac_intermediate` is used to process all but the last chunk. All message chunks to be processed by `ica_3des_cmac_intermediate` must have a size that is a multiple of the cipher block size (a multiple of 8 bytes for 3DES).

Note that `ica_3des_cmac_intermediate` has no direction argument. This function can be used during authentication and during authenticity verification.

### Format

```
unsigned int ica_3des_cmac_intermediate(const unsigned char *message,
  unsigned long message_length,
  const unsigned char *key,
  unsigned char *iv);
```

### Required hardware support

KMAC-TDEA-192

### Parameters

**const unsigned char *message**
Pointer to a readable buffer of size greater than or equal to *message_length* bytes. This buffer contains a non-final part of a message to be authenticated, or of which the authenticity is to be verified.

**unsigned long message_length**
Length in bytes of the message part in *message*. This value must be a multiple of the cipher block size.

**const unsigned char *key**
Pointer to a valid 3DES key of 24 bytes in length.

**unsigned char *iv**
Pointer to a valid initialization vector of cipher block size (8 bytes for 3DES). For the first message part, this parameter must be set to a string of zeros. For processing the *n*-th message part, this parameter must be the resulting *iv* value of the `ica_3des_cmac_intermediate` applied to the (*n-1*)-th message part. This vector is overwritten during the function. The result value in *iv* can

be used as the initialization vector for a chained call to `ica_3des_cmac_initermediate` or to `ica_3des_cmac_last` with the same key.

### Return codes

**0**

Success

For return codes indicating exceptions, see “Return codes” on page 138.

## ica_3des_cmac_last

### Purpose

Authenticate data or verify the authenticity of data with an 3DES key using the Block Cipher Based Message Authentication Code (CMAC) mode, as described in NIST Special Publication 800-38B. `ica_3des_cmac_last` can be used to authenticate or verify the authenticity of a complete message or of the final part of a message, for which all preceding parts were processed with `ica_3des_cmac_intermediate`.

### Format

```
unsigned int ica_3des_cmac_last(const unsigned char *message,
  unsigned long message_length,
  unsigned char *mac,
  unsigned int mac_length,
  const unsigned char *key,
  unsigned char *iv,
  unsigned int direction);
```

### Required hardware support

KMAC-TDEA,-192
PCC-Compute-Last_block-CMAC-Using-TDEA-192

### Parameters

**const unsigned char *message**

Pointer to a readable buffer of size greater than or equal to *message_length* bytes. It contains a message or the final part of a message to be authenticated, or of which the authenticity is to be verified.

**unsigned long message_length**

Length in bytes of the message to be authenticated or verified.

**unsigned char *mac**

Pointer to a buffer of size greater than or equal to *mac_length* bytes. If *direction* is equal to 1, the buffer must be writable and a message authentication code for the message in *message* of size *mac_length* bytes is written to the buffer. If *direction* is equal to 0, the buffer must be readable and contain a message authentication code that is to be verified against the message in *message*.

**unsigned int mac_length**

Length in bytes of the message authentication code *mac* in bytes that is less than or equal to the cipher block size (8 bytes for 3DES). It is recommended to use a *mac_length* of 8.

**const unsigned char *key**

Pointer to a valid 3DES key of 24 bytes in length.

**unsigned char *iv**

Pointer to a valid initialization vector of cipher block size number of bytes. If *iv* is NULL, *message* is assumed to be the complete message to be processed. Otherwise, *message* is the final part of a composite message to be processed and *iv* contains the output vector resulting from processing all previous parts with chained calls to `ica_des_cmac_intermediate` (the value returned in *iv* of the `ica_des_cmac_intermediate` call applied to the penultimate message part.

**unsigned int direction**

**0**
Verify message authentication code.

**1**
Compute message authentication code for the message.

### Return codes

**0**
Success

**EFAULT**
If *direction* is equal to 0 and the verification of the message authentication code fails.

For return codes indicating exceptions, see "Return codes" on page 138.

## ica_3des_ctr

### Purpose

Encrypt or decrypt data with a triple-length DES key using Counter (CTR) mode, as described in NIST Special Publication 800-38A Chapter 6.5. With the counter mode, each message block of size cipher block size (8 bytes for 3DES) is combined with a counter value of the same size during encryption and decryption.

Starting with an initial counter value to be combined with the first message block, subsequent counter values to be combined with subsequent message blocks are derived from preceding counter values by an increment function. The increment function used in `ica_3des_ctr` is an arithmetic increment without carry on the *M* least significant bits in the counter, where *M* is a parameter to `ica_3des_ctr`.

### Format

```
unsigned int ica_3des_ctr(const unsigned char *in_data,
  unsigned char *out_data,
  unsigned long data_length,
  const unsigned char *key,
  unsigned char *ctr,
  unsigned int ctr_width,
  unsigned int direction);
```

### Required hardware support

KMCTR-TDEA-192

### Parameters

**const unsigned char *in_data**
Pointer to a readable buffer that contains the message to be encrypted or decrypted. The size of the message in bytes is *data_length*. The size of this buffer must be at least as large as *data_length*.

**unsigned char *out_data**
Pointer to a writable buffer to contain the resulting encrypted or decrypted message. The size of this buffer in bytes must be at least as large as *data_length*.

**unsigned long data_length**
Length in bytes of the message to be encrypted or decrypted, which resides at the beginning of *in_data*.

**const unsigned char *key**

Pointer to a valid 3DES key of 24 bytes in length.

**unsigned char *ctr**

Pointer to a readable and writable buffer of the same size as the cipher block in bytes. *ctr* contains an initialization value for a counter function that is replaced by a new value. The new value can be used as an initialization value for a counter function in a chained `ica_3des_ctr` call with the same key, if the *data_length* used in the preceding call is a multiple of the cipher block size.

**unsigned int ctr_width**

A number *M* between 8 and the cipher block size in bits. The value is used by the counter increment function, which increments a counter value by incrementing without carry the least significant *M* bits of the counter value. The value must be a multiple of 8 and smaller than 64. When in FIPS mode, an additional counter overflow check is performed, so that the given data length divided by 64 is not greater than $2^M$.

**unsigned int direction**

**0**

Use the decrypt function.

**1**

Use the encrypt function.

### Return codes

**0**

Success

For return codes indicating exceptions, see "Return codes" on page 138.

## ica_3des_ctrlist

### Purpose

Encrypt or decrypt data with an 3DES key using Counter (CTR) mode, as described in NIST Special Publication 800-38A ,Chapter 6.5. With the counter mode, each message block of the same size as the cipher block is combined with a counter value of the same size during encryption and decryption.

The `ica_3des_ctrlist` function assumes that a list *n* of precomputed counter values is provided where *n* is the smallest integer that is less than or equal to the message size divided by the cipher block size. This function is used to optimally utilize IBM Z hardware support for non-standard counter functions.

### Format

```
unsigned int ica_3des_ctrlist(const unsigned char *in_data,
  unsigned char *out_data,
  unsigned long data_length,
  const unsigned char *key,
  const unsigned char *ctrlist,
  unsigned int direction);
```

### Required hardware support

KMCTR-TDEA-192

### Parameters

**const unsigned char *in_data**

Pointer to a readable buffer that contains the message to be encrypted or decrypted. The size of the message in bytes is *data_length*. The size of this buffer must be at least as large as *data_length*.

**unsigned char *out_data**

Pointer to a writable buffer to contain the resulting encrypted or decrypted message. The size of this buffer in bytes must be at least as large as *data_length*.

**unsigned long data_length**

Length in bytes of the message to be encrypted or decrypted, which resides at the beginning of *in_data*.

Calls to `ica_3des_ctrlist` with the same key can be chained if:

- With the possible exception of the last call in the chain the *data_length* used is a multiple of the cipher block size.
- The *ctrlist* argument of each chained call contains a list of counters that follows the counters used in the preceding call.

**const unsigned char *key**

Pointer to a valid 3DES key of 24 bytes in length.

**const unsigned char *ctrlist**

Pointer to a readable buffer that is both of size greater than or equal to *data_length*, and a multiple of the cipher block size (8 bytes for 3DES). *ctrlist* should contain a list of precomputed counter values, each of the same size as the cipher block.

**unsigned int direction**

**0**

Use the decrypt function.

**1**

Use the encrypt function.

### Return codes

**0**

Success

For return codes indicating exceptions, see “Return codes” on page 138.

## ica_3des_ecb

### Purpose

Encrypt or decrypt data with an 3DES key using Electronic Code Book (ECB) mode, as described in NIST Special Publication 800-38A Chapter 6.1.

### Format

```
unsigned int ica_3des_ecb(const unsigned char *in_data,
  unsigned char *out_data,
  unsigned long data_length,
  const unsigned char *key,
  unsigned int direction);
```

### Required hardware support

KM-DEA-192

### Parameters

**const unsigned char *in_data**

Pointer to a readable buffer that contains the message to be encrypted or decrypted. The size of the message in bytes is *data_length*. The size of this buffer must be at least as large as *data_length*.

**unsigned char *out_data**
Pointer to a writeable buffer to contain the resulting encrypted or decrypted message. The size of this buffer in bytes must be at least as large as *data_length*.

**unsigned long data_length**
Length in bytes of the message to be encrypted or decrypted, which resides at the beginning of *in_data*. *data_length* must be a multiple of the cipher block size (8 bytes for 3DES).

**const unsigned char *key**
Pointer to a valid 3DES key of 24 bytes in length.

**unsigned int direction**

**0**
Use the decrypt function.

**1**
Use the encrypt function.

### Return codes

**0**
Success

For return codes indicating exceptions, see "Return codes" on page 138.

## ica_3des_ofb

### Purpose

Encrypt or decrypt data with an 3DES key using Output Feedback (OFB) mode, as described in NIST Special Publication 800-38A Chapter 6.4.

### Format

```
unsigned int ica_3des_ofb(const unsigned char *in_data,
  unsigned char *out_data,
  unsigned long data_length,
  const unsigned char *key,
  unsigned int key_length,
  unsigned char *iv,
  unsigned int direction);
```

### Required hardware support

KMO-TDEA-192

### Parameters

**const unsigned char *in_data**
Pointer to a readable buffer that contains the message to be encrypted or decrypted. The size of the message in bytes is *data_length*. The size of this buffer must be at least as large as *data_length*.

**unsigned char *out_data**
Pointer to a writable buffer that contains the resulting encrypted or decrypted message. The size of this buffer in bytes must be at least as large as *data_length*.

**unsigned long data_length**
Length in bytes of the message to be encrypted or decrypted, which resides at the beginning of *in_data*.

**const unsigned char *key**
Pointer to a valid 3DES key of 24 bytes in length.

**unsigned char *iv**

Pointer to a valid initialization vector of the same size as the cipher block in bytes (8 bytes for 3DES). This vector is overwritten during the function. If *data_length* is a multiple of the cipher block size (a multiple of 8 for 3DES), the result value in *iv* can be used as the initialization vector for a chained `ica_3des_ofb` call with the same key.

**unsigned int direction**

**0**

Use the decrypt function.

**1**

Use the encrypt function.

### Return codes

**0**

Success

For return codes indicating exceptions, see "Return codes" on page 138.

# Information retrieval functions

Use the provided functions to retrieve information about the libica version and the supported crypto mechanisms.

These functions are declared in: `include/ica_api.h`.

## ica_get_version

### Purpose

Return libica version information.

### Format

```
unsigned int ica_get_version(libica_version_info *version_info);
```

### Parameters

**libica_version_info *version_info**

Pointer to a *libica_version_info* structure. The structure is filled with the current libica version information.

### Return codes

**0**

Success

For return codes indicating exceptions, see "Return codes" on page 138.

## ica_get_build_version

### Purpose

This API returns a string that indicates a specific libica build version. It can be freely defined for example by distributors or vendors. The string can be fed from external builds, using for example:

```
make BUILD_VERSION="FIPS-build-1.2.3"
```

The default is: "UNSPECIFIED".

You can also retrieve this information using the **icainfo -v** command.

### Format

```
const char *ica_get_build_version(void);
```

### Return codes

None.

## ica_get_hw_info

### Purpose

Returns hardware information about the used processor.

### Format

```
int ica_get_hw_info(libica_hw_info *hw_info);
```

### Parameters

**libica_hw_info *hw_info**

### Return codes

**0**
Success

**EINVAL**
The value in **hw_info** is NULL.

**EIO**
The hardware information could not be determined.

For return codes indicating exceptions, see "Return codes" on page 138.

### Recommended usage

First call **ica_get_functionlist** with a NULL mechanism list, then allocate the mechanism list according to number of mechanisms in libica returned by that function, and then call **ica_get_functionlist** with the allocated mechanism list.

## ica_get_msa_level

### Purpose

Return the processor's highest message security assist level (MSA Extension). Refer to the **z/Architecture Principles of Operation** for details about MSA extensions.

### Format

```
int ica_get_msa_level(void);
```

### Return codes

**0**
If the MSA Extension could not be determined successfully.

**integer > 0**
Indicates the MSA Extension according to the **z/Architecture Principles of Operation**.

## ica_get_functionlist

### Purpose

Returns a list of crypto mechanisms supported by libica.

### Format

```
unsigned int ica_get_functionlist(libica_func_list_element *mech_list,
  unsigned int *mech_list_len);
```

### Parameters

**libica_func_list_element *mech_list**
Null or pointer to an array of at least as many **libica_func_list_element** structures as denoted in the ***mech_list_len** argument. If the value in the ***mech_list_len** argument is equal to or greater than the number of mechanisms available in libica then the **libica_func_list_element** structures in ***mech_list** are filled (in the order of the array indices) with information for the supported mechanisms. Otherwise the ***mech_list** argument remains unchanged.

**unsigned int *mech_list_len**
Pointer to an integer which contains the actual number of array elements (number of structures). If ***mech_list** was NULL the contents of ***mech_list_len** is replaced by the number of mechanisms available in libica.

### Return codes

**0**
Success

**EINVAL**
The value in **mech_list* is to small

For return codes indicating exceptions, see "Return codes" on page 138.

### Recommended usage

First call **ica_get_functionlist** with a NULL mechanism list, then allocate the mechanism list according to number of mechanisms in libica returned by that function, and then call **ica_get_functionlist** with the allocated mechanism list.

# FIPS mode functions

Several functions are available to retrieve information about FIPS mode and FIPS compliance.

- You can start implemented self-tests.
- You can query and return the results of the self-tests and retrieve information whether libica is running in FIPS mode.
- For each hardware function or mechanism you can retrieve an indication whether this function or mechanism is FIPS-compliant or not.

These functions are declared in: `include/ica_api.h`.

# ica_fips_status

## Purpose

Queries and returns a FIPS status that indicates, which self-tests were passed or failed, and whether libica is running in FIPS mode.

The output is an integer, which is interpreted as a series of 32 bits, where each bit is a flag. Each flag, if set, corresponds to one of the defined constants as described in "FIPS mode constants" on page 133. Each constant, in return indicates either a status, or whether a certain test has passed (flag or constant is not set) or failed (flag or constant is set).

For example, look at the following returned integer as a bitmap, where only the 12 rightmost bits are considered:

```
... 0001 0000 1000
       |      |
    2^8=256   2^3=8
```

In this example, we see that bits with values 8 and 256 are set, which means, that `ICA_FIPS_CRITICALFUNC 8` and `ICA_FIPS_BYPASS 256` are set. This in turn means, that the *Critical functions test* and the *Bypass test* failed.

## Format

```
int ica_fips_status(void);
```

## Return codes

**1**
libica is running in FIPS mode.

**0**
libica is not running in FIPS mode.

**integer other than 0 or 1**
Flags indicating the module status. See "FIPS mode constants" on page 133.

# ica_fips_powerup_tests

## Purpose

Triggers the implemented self-tests. Use the `ica_fips_status(void)` function to see which tests passed or failed (see "ica_fips_status" on page 116).

## Format

```
void ica_fips_powerup_tests(void);
```

## Return codes

None.

### ica_get_fips_indicator

#### Purpose

Returns a FIPS service indicator for each hardware function or any other mechanism, that is, an indication is provided whether this function or mechanism is FIPS-compliant or not. From this information, application developers can figure out, whether a libica API that they want to use is FIPS-compliant or not. This list is a static list and cannot be changed by an application and can only be used for information purposes.

You can use the **`icainfo -f`** command to display an output which interprets this FIPS service indicator (see "icainfo -f" on page 141).

#### Format

```
unsigned int ica_get_fips_indicator(libica_fips_indicator_element *fips_list,
  unsigned int *fips_list_len);
```

#### Parameters

**libica_fips_indicator_element *fips_list**

NULL or pointer to an array of at least as many **`libica_fips_indicator_element`** structures as denoted in the **`*fips_list_len`** argument. If the value in the **`*fips_list_len`** argument is equal to or greater than the number of mechanisms available in libica, then the **`libica_fips_indicator_element`** structures in **`*fips_list`** are filled (in the order of the array indices) with information for the FIPS-compliant mechanisms. Otherwise the **`*fips_list`** argument remains unchanged.

**unsigned int *fips_list_len**

Pointer to an integer which contains the actual number of array elements (number of structures). If **`*fips_list`** was NULL, the contents of **`*fips_list_len`** is replaced by the number of FIPS-compliant mechanisms available in libica.

#### Return codes

**0**

Success

**EINVAL**

If at least one invalid parameter is given or if the application-provided buffer size (given in parameter **`fips_list_len`**) is too small for the list to be returned.

## SIMD support

The IBM z14 and the IBM z13 machines added various vector instruction facilities to their processor's instruction set. These are single instruction, multiple data (SIMD) vector instructions that perform the same operation on multiple data points (the vector elements) simultaneously. Thus, starting with IBM z14 and libica version 3.3, you can exploit this data-level parallelism to improve performance of multi-precision arithmetic.

So starting with libica version 3.3 and IBM z14, you can use two APIs to exploit this parallelism in public key cryptography functions for computationally intensive squaring and multiplication operations for numbers up to a size of 512 bits.

#### Input format

For both APIs, the input numbers are represented in radix 264 with little-endian digit order, that is, the least-significant digit is stored at array element zero.

That is:

$$a = a_7(2^{64})^7 + a_6(2^{64})^6 + a_5(2^{64})^5 + a_4(2^{64})^4 + a_3(2^{64})^3 + a_2(2^{64})^2 + a_1(2^{64}) + a_0;$$

with:

$$a_i \in \{0,...,2^{64}-1\}$$

is represented by:

```
uint64_t a[8] = {a0; a1; a2; a3; a4; a5; a6; a7};
```

All input must be zero-padded. The output is zero-padded.

# ica_mp_mul512

## Purpose

Computes the 1024-bit product **r** of the 512-bit factors **a** and **b**, that is `r = ab`.

## Format

```
int ica_mp_mul512(uint64_t r[16],
  const uint64_t a[8],
  const uint64_t b[8]);
```

## Required hardware support

All vector instructions required for using this function are only available in the instruction set starting with IBM z14 machines.

## Parameters

**uint64_t r[16]**
Pointer to the 1024-bit product resulting from factors a[8] and b[8].

**const uint64_t a[8]**
Pointer to the first 512-bit factor.

**const uint64_t b[8]**
Pointer to the second 512-bit factor.

## Return codes

**0**
Success

**≠ 0**
Vector facilities are not enabled.

For return codes indicating exceptions, see "Return codes" on page 138.

# ica_mp_sqr512

## Purpose

Computes the 1024-bit square **r** of the 512-bit base **a**, that is $r = a^2$.

### Format

```
int ica_mp_sqr512(uint64_t r[16],
  const uint64_t a[8]);
```

### Required hardware support

All vector instructions required for using this function are only available in the instruction set starting with IBM z14 machines.

### Parameters

**uint64_t r[16]**
Pointer to the 1024-bit square resulting from the 512-bit base a[8].

**const uint64_t a[8]**
Pointer to the 512-bit base a[8].

### Return codes

**0**
Success

**≠ 0**
Vector facilities are not enabled.

For return codes indicating exceptions, see "Return codes" on page 138.

## Deprecated functions

Some of the libica application programming interfaces are meanwhile deprecated due to their insufficient security strength. For compatibility reasons, libica continues to offer these functions. However, it is recommended to replace them with more secure APIs as indicated.

The list of deprecated functions currently comprises all DES functions and the SHA1 function.

- Instead of the DES functions, use the corresponding AES functions ("AES functions" on page 71).
- Instead of the SHA1 function (`ica_sha1`), use one of the hash APIs listed in "Secure hash operations" on page 23.

These deprecated functions are also included in: `include/ica_api.h`.

### DES functions

DES functions perform encryption and decryption and computation or verification of message authentication codes using a DES (DEA) key. A DES key has a size of 8 bytes. Each byte of a DES key contains one parity bit, such that each 64-bit DES key contains only 56 security-relevant bits. The cipher block size for DES is 8 bytes.

To securely apply DES encryption to messages that are longer than the cipher block size, modes of operation can be used to chain multiple encryption, decryption, or authentication operations. Most modes of operation require an initialization vector as additional input. As long as the messages are encrypted or decrypted using such a mode of operation, and have a size that is a multiple of a particular block size (mostly the cipher block size), the functions encrypting or decrypting according to a mode of operation also compute an output vector. This output vector can be used as the initialization vector of a chained encryption or decryption operation in the same mode with the same block size and the same key.

When decrypting a cipher text, these values used for the decryption function must match the corresponding settings of the encryption function that transformed the plain text into the cipher text:

- The mode of operation

- The key
- The initialization vector (if applicable)
- For the `ica_des_cfb` function, the *lcfb* parameter

# ica_des_cbc

## Purpose

Encrypt or decrypt data with a DES key using Cipher Block Chaining (CBC) mode, as described in NIST Special Publication 800-38A Chapter 6.2.

## Format

```
unsigned int ica_des_cbc(const unsigned char *in_data,
  unsigned char *out_data,
  unsigned long data_length,
  const unsigned char *key,
  unsigned char *iv,
  unsigned int direction);
```

## Required hardware support

KMC-DEA

## Parameters

**const unsigned char *in_data**
Pointer to a readable buffer that contains the message to be encrypted or decrypted. The size of the message in bytes is *data_length*. This buffer must be at least as large as *data_length*.

**unsigned char *out_data**
Pointer to a writable buffer to contain the resulting encrypted or decrypted message. The size of this buffer in bytes must be at least as large as *data_length*.

**unsigned long data_length**
Length in bytes of the message to be encrypted or decrypted, which resides at the beginning of *in_data*. *data_length* must be a multiple of the cipher block size (a multiple of 8 bytes for DES).

**const unsigned char *key**
Pointer to a valid DES key of 8 bytes in length.

**unsigned char *iv**
Pointer to a valid initialization vector of cipher block size number of bytes (8 bytes for DES). This vector is overwritten by this function. The result value in *iv* can be used as the initialization vector for a chained `ica_des_cbc` or `ica_des_cbc_cs` call with the same key.

**unsigned int direction**

**0**
Use the decrypt function.

**1**
Use the encrypt function.

## Return codes

**0**
Success

For return codes indicating exceptions, see "Return codes" on page 138.

# ica_des_cbc_cs

## Purpose

Encrypt or decrypt data with a DES key using Cipher Block Chaining with Ciphertext Stealing (CBC-CS) mode, as described in NIST Special Publication 800-38A, Chapter 6.2 and the Addendum to NIST Special Publication 800-38A on *Recommendation for Block Cipher Modes of Operation: Three Variants of Ciphertext Stealing for CBC Mode*.

`ica_des_cbc_cs` can be used to encrypt or decrypt the last chunk of a message consisting of multiple chunks, where all chunks except the last one are encrypted or decrypted by chained calls to `ica_des_cbc`. To do this, the resulting *iv* of the last call to `ica_des_cbc` is fed into the *iv* of the `ica_des_cbc_cs` call, provided that the chunk is greater than the cipher block size (8 bytes for DES).

## Format

```
unsigned int ica_des_cbc_cs(const unsigned char *in_data,
  unsigned char *out_data,
  unsigned long data_length,
  const unsigned char *key,
  unsigned char *iv,
  unsigned int direction,
  unsigned int variant);
```

## Required hardware support

KMC-DEA

## Parameters

**const unsigned char *in_data**
Pointer to a readable buffer that contains the message to be encrypted or decrypted. The size of the message in bytes is *data_length*. The size of this buffer must be at least as large as the *data_length*.

**unsigned char *out_data**
Pointer to a writable buffer to contain the resulting encrypted or decrypted message. This buffer must be at least as large as *data_length*.

**unsigned long data_length**
Length in bytes of the message to be encrypted or decrypted, which resides at the beginning of *in_data*. *data_length* must be greater than or equal to the cipher block size (8 bytes for DES).

**const unsigned char *key**
Pointer to a valid DES key of 8 bytes in length.

**unsigned char *iv**
Pointer to a valid initialization vector of cipher block size number of bytes. This vector is overwritten during the function. For *variant* equal to 1 or *variant* equal to 2, the result value in *iv* can be used as the initialization vector for a chained `ica_des_cbc` or `ica_des_cbc_cs` call with the same key, if *data_length* is a multiple of the cipher block size.

**unsigned int direction**

**0**
Use the decrypt function.

**1**
Use the encrypt function.

**unsigned int variant**

**1**
Use variant CBC-CS1 of the Addendum to NIST Special Publication 800-38A to encrypt or decrypt the message: always keep last two blocks in order.

**2**

Use variant CBC-CS2 of the Addendum to NIST Special Publication 800-38A to encrypt or decrypt the message: switch order of the last two blocks if *data_length* is not a multiple of the cipher block size (a multiple of 8 bytes for DES).

**3**

Use variant CBC-CS3 of the Addendum to NIST Special Publication 800-38A to encrypt or decrypt the message: always switch order of the last two blocks.

### Return codes

**0**

Success

For return codes indicating exceptions, see "Return codes" on page 138.

## ica_des_cfb

### Purpose

Encrypt or decrypt data with a DES key using Cipher Feedback (CFB) mode, as described in NIST Special Publication 800-38A Chapter 6.3.

### Format

```
unsigned int ica_des_cfb(const unsigned char *in_data,
  unsigned char *out_data,
  unsigned long data_length,
  const unsigned char *key,
  unsigned char *iv,
  unsigned int lcfb,
  unsigned int direction);
```

### Required hardware support

KMF-DEA

### Parameters

**const unsigned char *in_data**

Pointer to a readable buffer that contains the message to be encrypted or decrypted. The size of the message in bytes is *data_length*. The size of this buffer must be at least as large as the *data_length* parameter.

**unsigned char *out_data**

Pointer to a writable buffer to contain the resulting encrypted or decrypted message. The size of this buffer in bytes must be at least as large as the *data_length* parameter.

**unsigned long data_length**

Length in bytes of the message to be encrypted or decrypted, which resides at the beginning of *in_data*.

**const unsigned char *key**

Pointer to a valid DES key of 8 bytes in length.

**unsigned char *iv**

Pointer to a valid initialization vector of cipher block size bytes (8 bytes for DES). This vector is overwritten during the function. The result value in *iv* can be used as the initialization vector for a chained `ica_des_cfb` call with the same key, if *data_length* in the preceding call is a multiple of the *lcfb* parameter.

**unsigned int lcfb**
Length in bytes of the cipher feedback, which is a value greater than or equal to 1 and less than or equal to the cipher block size (8 bytes for DES).

**unsigned int direction**

**0**
Use the decrypt function.

**1**
Use the encrypt function.

### Return codes

**0**
Success

For return codes indicating exceptions, see "Return codes" on page 138.

## ica_des_cmac

### Purpose

Authenticate data or verify the authenticity of data with a DES key using the Block Cipher Based Message Authentication Code (CMAC) mode, as described in NIST Special Publication 800-38B. `ica_des_cmac` can be used to authenticate or verify the authenticity of a complete message.

### Format

```
unsigned int ica_des_cmac(const unsigned char *message,
  unsigned long message_length,
  unsigned char *mac,
  unsigned int mac_length,
  const unsigned char *key,
  unsigned int direction);
```

### Required hardware support

KMAC-DEA
PCC-Compute-Last_block-CMAC-Using-DEA

### Parameters

**const unsigned char *message**
Pointer to a readable buffer of size greater than or equal to *message_length* bytes. This buffer contains a message to be authenticated or of which the authenticity is to be verified.

**unsigned long message_length**
Length in bytes of the message to be authenticated or verified.

**unsigned char *mac**
Pointer to a buffer of size greater than or equal to *mac_length* bytes. If *direction* is equal to 1, the buffer must be writable and a message authentication code for the message in *message* of size *mac_length* bytes is written to the buffer. If *direction* is equal to 0, the buffer must be readable and contain a message authentication code to be verified against the message in *message*.

**unsigned int mac_length**
Length in bytes of the message authentication code *mac*, which is less than or equal to the cipher block size (8 bytes for DES). It is recommended to use a *mac_length* of 8.

**const unsigned char *key**
Pointer to a valid DES key of 8 bytes in length.

**unsigned int direction**

**0**
Verify message authentication code.

**1**
Compute message authentication code for the message.

### Return codes

**0**
Success

**EFAULT**
If *direction* is equal to 0 and the verification of the message authentication code fails.

For return codes indicating exceptions, see “Return codes” on page 138.

## ica_des_cmac_intermediate

### Purpose

Authenticate data or verify the authenticity of data with a DES key using the Block Cipher Based Message Authentication Code (CMAC) mode, as described in NIST Special Publication 800-38B. `ica_des_cmac_intermediate` and `ica_des_cmac_last` can be used when the message to be authenticated or to be verified using CMAC is supplied in multiple chunks. `ica_des_cmac_intermediate` is used to process all but the last chunk. All message chunks to be processed by `ica_des_cmac_intermediate` must have a size that is a multiple of the cipher block size (8 bytes for DES).

Note that `ica_des_cmac_intermediate` has no direction argument. This function can be used during authentication and during authenticity verification.

### Format

```
unsigned int ica_des_cmac_intermediate(const unsigned char *message,
  unsigned long message_length,
  const unsigned char *key,
  unsigned char *iv);
```

### Required hardware support

KMAC-DEA

### Parameters

**const unsigned char *message**
Pointer to a readable buffer of size greater than or equal to *message_length* bytes. This buffer contains a non-final part of a message to be authenticated, or of which the authenticity is to be verified.

**unsigned long message_length**
Length in bytes of the message part in *message*. This value must be a multiple of the cipher block size.

**const unsigned char *key**
Pointer to a valid DES key of 8 bytes in length.

**unsigned char *iv**
Pointer to a valid initialization vector of cipher block size bytes (8 bytes for DES). For the first message part, this parameter must be set to a string of zeros. For processing the *n*-th message part, this parameter must be the resulting *iv* value of the `ica_des_cmac_intermediate` function applied to the (*n-1*)-th message part. This vector is overwritten during the function. The result value in *iv*

can be used as the initialization vector for a chained call to `ica_des_cmac_initermediate`, or to `ica_des_cmac_last` with the same key.

### Return codes

**0**

Success

For return codes indicating exceptions, see “Return codes” on page 138.

## ica_des_cmac_last

### Purpose

Authenticate data or verify the authenticity of data with a DES key using the Block Cipher Based Message Authentication Code (CMAC) mode, as described in NIST Special Publication 800-38B. `ica_des_cmac_last` can be used to authenticate or verify the authenticity of a complete message or of the final part of a message for which all preceding parts were processed with `ica_des_cmac_intermediate`.

### Format

```
unsigned int ica_des_cmac_last(const unsigned char *message,
  unsigned long message_length,
  unsigned char *mac,
  unsigned int mac_length,
  const unsigned char *key,
  unsigned char *iv,
  unsigned int direction);
```

### Required hardware support

KMAC-DEA

PCC-Compute-Last_block-CMAC-Using-DEA

### Parameters

**const unsigned char *message**

Pointer to a readable buffer of size greater than or equal to *message_length* bytes. This buffer contains a message or the final part of a message, to be either authenticated or of which the authenticity is to be verified.

**unsigned long message_length**

Length in bytes of the message to be authenticated or verified.

**unsigned char *mac**

Pointer to a buffer of size greater than or equal to *mac_length* bytes. If *direction* is equal to 1, the buffer must be writable and a message authentication code for the message in *message* of size *mac_length* bytes is written to the buffer. If *direction* is equal to 0, the buffer must be readable and contain a message authentication code that is verified against the message in *message*.

**unsigned int mac_length**

Length in bytes of the message authentication code *mac* that is less than or equal to the cipher block size (8 bytes for DES). It is recommended to use a *mac_length* of 8.

**const unsigned char *key**

Pointer to a valid DES key of 8 bytes in length.

**unsigned char *iv**

Pointer to a valid initialization vector of cipher block size number of bytes. If *iv* is NULL, *message* is assumed to be the complete message to be processed. Otherwise, *message* is the final part of a composite message to be processed and *iv* contains the output vector resulting from processing all previous parts with chained calls to `ica_des_cmac_intermediate` (the value returned in *iv* of the `ica_des_cmac_intermediate` call applied to the penultimate message part).

**unsigned int direction**

**0**
Verify message authentication code.

**1**
Compute message authentication code for the message.

### Return codes

**0**
Success

**EFAULT**
If *direction* is equal to 0 and the verification of the message authentication code fails.

For return codes indicating exceptions, see "Return codes" on page 138.

## ica_des_ctr

### Purpose

Encrypt or decrypt data with a DES key using Counter (CTR) mode, as described in NIST Special Publication 800-38A Chapter 6.5. With the counter mode, each message block of the same size as the cipher block (8 bytes for DES) is combined with a counter value of the same size during encryption and decryption.

Starting with an initial counter value to be combined with the first message block, subsequent counter values to be combined with subsequent message blocks are derived from preceding counter values by an increment function. The increment function used in `ica_des_ctr` is an arithmetic increment without carry on the *M* least significant bits in the counter, where *M* is a parameter to `ica_des_ctr`.

### Format

```
unsigned int ica_des_ctr(const unsigned char *in_data,
  unsigned char *out_data,
  unsigned long data_length,
  const unsigned char *key,
  unsigned char *ctr,
  unsigned int ctr_width,
  unsigned int direction);
```

### Required hardware support

KMCTR-DEA

### Parameters

**const unsigned char *in_data**
Pointer to a readable buffer that contains the message to be encrypted or decrypted. The size of the message in bytes is *data_length*. The size of this buffer must be at least as large as *data_length*.

**unsigned char *out_data**
Pointer to a writable buffer to contain the resulting encrypted or decrypted message. The size of this buffer in bytes must be at least as large as *data_length*.

**unsigned long data_length**
Length in bytes of the message to be encrypted or decrypted, which resides at the beginning of *in_data*.

**const unsigned char *key**

Pointer to a valid DES key of 8 bytes in length.

**unsigned char *ctr**

Pointer to a readable and writable buffer of the same size as the cipher block in bytes. *ctr* contains an initialization value for a counter function, and it is replaced by a new value. That new value can be used as the initialization value for a counter function in a chained `ica_des_ctr` call with the same key, if the *data_length* used in the preceding call is a multiple of the cipher block size.

**unsigned int ctr_width**

A number *M* between 8 and the cipher block size in bits. This value is used by the counter increment function, which increments a counter value by incrementing without carry the least significant *M* bits of the counter value. The value must be a multiple of 8 and smaller than 64. When in FIPS mode, an additional counter overflow check is performed, so that the given data length divided by 64 is not greater than $2^M$.

**unsigned int direction**

**0**

Use the decrypt function.

**1**

Use the encrypt function.

### Return codes

**0**

Success

For return codes indicating exceptions, see "Return codes" on page 138.

## ica_des_ctrlist

### Purpose

Encrypt or decrypt data with a DES key using Counter (CTR) mode, as described in NIST Special Publication 800-38A ,Chapter 6.5. With the counter mode, each message block of the same size as the cipher block is combined with a counter value of the same size during encryption and decryption.

The `ica_des_ctrlist` function assumes that a list *n* of precomputed counter values is provided, where *n* is the smallest integer that is less than or equal to the message size divided by the cipher block size. This function is used to optimally utilize IBM Z hardware support for non-standard counter functions.

### Format

```
unsigned int ica_des_ctrlist(const unsigned char *in_data,
  unsigned char *out_data,
  unsigned long data_length,
  const unsigned char *key,
  const unsigned char *ctrlist,
  unsigned int direction);
```

### Required hardware support

KMCTR-DEA

### Parameters

**const unsigned char *in_data**

Pointer to a readable buffer that contains the message to be encrypted or decrypted. The size of the message in bytes is *data_length*. The size of this buffer must be at least as large as *data_length*.

**unsigned char *out_data**
Pointer to a writable buffer to contain the resulting encrypted or decrypted message. The size of this buffer in bytes must be at least as large as *data_length*.

**unsigned long data_length**
Length in bytes of the message to be encrypted or decrypted, which resides at the beginning of *in_data*.

Calls to `ica_des_ctrlist` with the same key can be chained if:

- With the possible exception of the last call in the chain the *data_length* used is a multiple of the cipher block size.
- The *ctrlist* argument of each chained call contains a list of counters that follows the counters used in the preceding call.

**const unsigned char *key**
Pointer to a valid DES key of 8 bytes in length.

**const unsigned char *ctrlist**
Pointer to a readable buffer of a size greater than or equal to *data_length*, and a multiple of the cipher block size (8 bytes for DES). *ctrlist* should contain a list of precomputed counter values, each of the same size as the cipher block.

**unsigned int direction**

**0**
Use the decrypt function.

**1**
Use the encrypt function.

### Return codes

**0**
Success

For return codes indicating exceptions, see “Return codes” on page 138.

## ica_des_ecb

### Purpose

Encrypt or decrypt data with a DES key using Electronic Code Book (ECB) mode, as described in NIST Special Publication 800-38A Chapter 6.1.

### Format

```
unsigned int ica_des_ecb(const unsigned char *in_data,
  unsigned char *out_data,
  unsigned long data_length,
  const unsigned char *key,
  unsigned int direction);
```

### Required hardware support

KM-DEA

### Parameters

**const unsigned char *in_data**
Pointer to a readable buffer that contains the message to be encrypted or decrypted. The size of the message in bytes is *data_length*. The size of this buffer must be at least as large as *data_length*.

**unsigned char *out_data**

Pointer to a writeable buffer to contain the resulting encrypted or decrypted message. The size of this buffer in bytes must be at least as large as *data_length*.

**unsigned long data_length**

Length in bytes of the message to be encrypted or decrypted, which resides at the beginning of *in_data*. *data_length* must be a multiple of the cipher block size (8 bytes for DES).

**const unsigned char *key**

Pointer to a valid DES key of 8 bytes in length.

**unsigned int direction**

**0**

Use the decrypt function.

**1**

Use the encrypt function.

### Return codes

**0**

Success

For return codes indicating exceptions, see “Return codes” on page 138.

## ica_des_ofb

### Purpose

Encrypt or decrypt data with a DES key using Output Feedback (OFB) mode, as described in NIST Special Publication 800-38A Chapter 6.4.

### Format

```
unsigned int ica_des_ofb(const unsigned char *in_data,
  unsigned char *out_data,
  unsigned long data_length,
  const unsigned char *key,
  unsigned int key_length,
  unsigned char *iv,
  unsigned int direction);
```

### Required hardware support

KMO-DEA

### Parameters

**const unsigned char *in_data**

Pointer to a readable buffer that contains the message to be encrypted or decrypted. The size of the message in bytes is *data_length*. The size of this buffer must be at least as large as *data_length*.

**unsigned char *out_data**

Pointer to a writable buffer that contains the resulting encrypted or decrypted message. The size of this buffer must be at least as large as *data_length*.

**unsigned long data_length**

Length in bytes of the message to be encrypted or decrypted, which resides at the beginning of *in_data*.

**const unsigned char *key**

Pointer to a valid DES key of 8 bytes in length.

**unsigned char *iv**

Pointer to a valid initialization vector of the same size as the cipher block in bytes (8 bytes for DES). This vector is overwritten during the function. If *data_length* is a multiple of the cipher block size (8 bytes for DES), the result value in *iv* can be used as the initialization vector for a chained `ica_des_ofb` call with the same key.

**unsigned int direction**

**0**

Use the decrypt function.

**1**

Use the encrypt function.

## Return codes

**0**

Success

For return codes indicating exceptions, see "Return codes" on page 138.

# ica_sha1

## Purpose

Performs a secure hash operation on the input data using the SHA-1 algorithm.

## Format

```
unsigned int ica_sha1(unsigned int message_part,
  unsigned int input_length,
  const unsigned char *input_data,
  sha_context_t *sha_context,
  unsigned char *output_data);
```

## Required hardware support

KIMD-SHA-1 and KLMD-SHA-1

## Parameters

**unsigned int message_part**

The message chaining state. This parameter must be one of the following values:

**SHA_MSG_PART_ONLY**

A single hash operation

**SHA_MSG_PART_FIRST**

The first part

**SHA_MSG_PART_MIDDLE**

The middle part

**SHA_MSG_PART_FINAL**

The last part

**unsigned int input_length**

Length in bytes of the input data to be hashed using the SHA-1 algorithm.

**const unsigned char *input_data**

Pointer to the input data to be hashed. This pointer must not be zero. So even in case of zero size message data, it must be set to a valid value.

**sha_context_t *sha_context**

Pointer to the SHA-1 context structure used to store intermediate values needed when chaining is used. The contents are ignored for message part SHA_MSG_PART_ONLY and SHA_MSG_PART_FIRST. This structure must contain the returned value of the preceding call to `ica_sha1` for message part SHA_MSG_PART_MIDDLE and SHA_MSG_PART_FINAL. For message part SHA_MSG_PART_FIRST and SHA_MSG_PART_FINAL, the returned value can be used for a chained call of `ica_sha1`. Therefore, the application must not modify the contents of this structure in between chained calls.

**unsigned char *output_data**

Pointer to the buffer to contain the resulting hash data. The resulting output data has a length of `SHA_HASH_LENGTH`. Make sure that the buffer is at least this size.

## Return codes

**0**

Success

For return codes indicating exceptions, see "Return codes" on page 138.

# Chapter 4. libica constants, type definitions, data structures, and return codes

Use these constants, type definitions, data structures, and return codes when you program with the libica APIs.

The APIs are described in Chapter 3, “Application programming interfaces ,” on page 11. To use them, include `ica_api.h` in your programs.

## libica constants

The constants listed in this topic are provided and valid for the current libica version.

```
#define ICA_ENCRYPT 1
```

```
#define ICA_DECRYPT 0
```

```
#define ICA_DRBG_NEW_STATE_HANDLE NULL
```

### FIPS mode constants

/* ’FIPS mode active’-flag */

```
#define ICA_FIPS_MODE 1
```

**Powerup-test-failed flags**

/* Cryptographic algorithm test (KAT or pair-wise consistency test) */

```
#define ICA_FIPS_CRYPTOALG 2
```

/* Critical functions test (N/A) */

```
#define ICA_FIPS_CRITICALFUNC 8
```

**Conditional-test-failed flags**

/* Pair-wise consistency test for public & private keys (N/A) */

```
#define ICA_FIPS_CONSISTENCY 16
```

/* Software/Firmware load test (N/A) */

```
#define ICA_FIPS_LOAD 32
```

/* Manual key entry test (N/A) */

```
#define ICA_FIPS_KEYENTRY 64
```

/* Continuous random number generator test */

```
#define ICA_FIPS_RNG 128
```

/* Bypass test (N/A) */

```
#define ICA_FIPS_BYPASS 256
```

# Type definitions

These type definitions are available to ensure compatibility with libica version 1 types.

```
typedef ica_des_vector_t ICA_DES_VECTOR;
```

```
typedef ica_des_key_single_t ICA_KEY_DES_SINGLE;
```

```
typedef ica_des_key_triple_t ICA_KEY_DES_TRIPLE;
```

```
typedef ica_aes_vector_t ICA_AES_VECTOR;
```

```
typedef ica_aes_key_single_t ICA_KEY_AES_SINGLE;
```

```
typedef ica_aes_key_len_128_t ICA_KEY_AES_LEN128;
```

```
typedef ica_aes_key_len_192_t ICA_KEY_AES_LEN192;
```

```
typedef ica_aes_key_len_256_t ICA_KEY_AES_LEN256;
```

```
typedef sha_context_t SHA_CONTEXT;
```

```
typedef sha256_context_t SHA256_CONTEXT;
```

```
typedef sha512_context_t SHA512_CONTEXT;
```

```
typedef unsigned char ica_des_vector_t[8];
```

```
typedef unsigned char ica_des_key_single_t[8];
```

```
typedef unsigned char ica_key_t[8];
```

```
typedef unsigned char ica_aes_vector_t[16];
```

```
typedef unsigned char ica_aes_key_single_t[8];
```

```
typedef unsigned char ica_aes_key_len_128_t[16];
```

```
typedef unsigned char ica_aes_key_len_192_t[24];
```

```
typedef unsigned char ica_aes_key_len_256_t[32];
```

```
typedef struct ica_drbg_mech ica_drbg_mech_t;
```

```
typedef struct ica_drbg ica_drbg_t;
```

# Data structures

These structures are used in the API of the current libica version.

For the definitions of older functions, see previous versions of this book. The older functions are no longer recommended for use, but they are supported.

```
typedef struct {
unsigned int key_length;
unsigned char* modulus;
unsigned char* exponent;
} ica_rsa_key_mod_expo_t;
```

```
typedef struct {
unsigned int key_length;
unsigned char* p;
unsigned char* q;
unsigned char* dp;
unsigned char* dq;
unsigned char* qInverse;
} ica_rsa_key_crt_t;
```

```
typedef struct {
unsigned int mech_mode_id;
unsigned int flags;
unsigned int property;
} libica_func_list_element;
```

```
typedef struct {
unsigned char vendor_id[16];
unsigned char machine_type[16];
} libica_hw_info;
```

```
typedef struct kma_ctx_t kma_ctx;
```

- `mech_mode_id`: Unique mechanism ID for each mechanism implemented in libica, as follows:

```

#define SHA1              1
#define SHA224            2
#define SHA256            3
#define SHA384            4
#define SHA512            5
#define SHA3_224          6
#define SHA3_256          7
#define SHA3_384          8
#define SHA3_512          9
#define G_HASH           10
#define SHAKE_128        11
#define SHAKE_256        12
#define DES_ECB          20
#define DES_CBC          21
#define DES_CBC_CS       22
#define DES_OFB          23
#define DES_CFB          24
#define DES_CTR          25
#define DES_CTRLST       26
#define DES_CBC_MAC      27
#define DES_CMAC         28
#define DES3_ECB         41
#define DES3_CBC         42
#define DES3_CBC_CS      43
#define DES3_OFB         44
#define DES3_CFB         45
#define DES3_CTR         46
#define DES3_CTRLST      47
#define DES3_CBC_MAC     48
#define DES3_CMAC        49
#define AES_ECB          60
#define AES_CBC          61
#define AES_CBC_CS       62
#define AES_OFB          63
#define AES_CFB          64
#define AES_CTR          65
#define AES_CTRLST       66
#define AES_CBC_MAC      67
#define AES_CMAC         68
#define AES_CCM          69
#define AES_GCM          70
#define AES_XTS          71
#define AES_GCM_KMA      72
#define P_RNG            80
#define EC_DH            85
#define EC_DSA_SIGN      86
#define EC_DSA_VERIFY    87
#define EC_KGEN          88
```

```
#define RSA_ME          90
#define RSA_CRT         91
#define RSA_KEY_GEN_ME  92
#define RSA_KEY_GEN_CRT 93
#define SHA512_DRNG     94
#define SHA512_224      95
#define SHA512_256      96

#define ED25519_KEYGEN  100
#define ED25519_SIGN    101
#define ED25519_VERIFY  102
#define ED448_KEYGEN    103
#define ED448_SIGN      104
#define ED448_VERIFY    105
#define X25519_KEYGEN   106
#define X25519_DERIVE   107
#define X448_KEYGEN     108
#define X448_DERIVE     109
```

For more details regarding these mechanisms, refer to *openCryptoki - An Open Source Implementation of PKCS #11*.

*** flags**

This flag represents the type of hardware/software support for each mechanism.

**#define ICA_FLAG_SHW 4**

Static hardware support (operations on CPACF). Hardware support will be available unless a hardware error occurs.

**#define ICA_FLAG_DHW 2**

Dynamic hardware support (operations on crypto cards). Hardware support will be available unless the hardware is reconfigured.

**#define ICA_FLAG_SW 1**

Software support. If both static and dynamic hardware support as well as software support are available, then software support is used as fall back if hardware support fails.

*** property**

This property field is optional depending on the mechanism. It is used to declare mechanism specific parameters, such as key sizes for RSA and AES.

For RSA mechanisms:

**- bit 0**

512 bit key size support

**- bit 1**

1024 bit key size support

**- bit 2**

2048 bit key size support

**- bit 3**

4096 bit key size support

For AES mechanisms:

**- bit 0**

128 bit key size support

**- bit 1**

192 bit key size support

**- bit 2**

256 bit key size support

For all non-RSA/AES mechanisms this field is empty.

Take note of these considerations:

- The buffers pointed to by members of type *unsigned char ** must be manually allocated and deallocated by the user.

- Key parts must always be right-aligned in their fields.
- All buffers pointed to by members *modulus* and *exponent* in struct *ica_rsa_key_mod_expo_t* must be of length *key_length*.
- All buffers pointed to by members *p*, *q*, *dp*, *dq*, and *qInverse* in struct *ica_rsa_key_crt_t* must be of size *key_length* / 2 or larger.
- In the struct *ica_rsa_key_crt_t*, the buffers *p*, *dp*, and *qInverse* must contain 8 bytes of zero padding in front of the actual values.
- If an exponent is set in struct *ica_rsa_key_mod_expo_t* as part of a public key for key generation, be aware that due to a restriction in OpenSSL, the public exponent cannot be larger than a size of unsigned long. Therefore, you must have zeros left-padded in the buffer pointed to by *exponent* in the struct *ica_rsa_key_mod_expo_t* struct. Be aware that this buffer also must be of size *key_length*.
- This *key_length* value should be calculated from the length of the modulus in bits, according to this calculation:

  ```
  key_length = (modulus_bits + 7) / 8
  ```

```
typedef struct {
        uint64_t runningLength;
        unsigned char shaHash[LENGTH_SHA_HASH];
} sha_context_t;
```

```
typedef struct {
        uint64_t runningLength;
        unsigned char sha256Hash[LENGTH_SHA256_HASH];
} sha256_context_t;
```

```
typedef struct {
        uint64_t runningLengthHigh;
        uint64_t runningLengthLow;
        unsigned char sha512Hash[LENGTH_SHA512_HASH];
} sha512_context_t;
```

```
typedef struct {
        uint64_t runningLength;
        unsigned char sha3_224Hash[SHA3_224_HASH_LENGTH];
} sha3_224_context_t;
```

```
typedef struct {
        uint64_t runningLength;
        unsigned char sha3_256Hash[SHA3_256_HASH_LENGTH];
} sha3_256_context_t;
```

```
typedef struct {
        uint64_t runningLengthHigh;
        uint64_t runningLengthLow;
        unsigned char sha3_384Hash[SHA3_384_HASH_LENGTH];
} sha3_384_context_t;
```

```
typedef struct {
        uint64_t runningLengthHigh;
        uint64_t runningLengthLow;
        unsigned char sha3_512Hash[SHA3_512_HASH_LENGTH];
} sha3_512_context_t;
```

```
typedef struct {
        uint64_t runningLengthHigh;
        uint64_t runningLengthLow;
        unsigned int output_length;
```

```
        unsigned char shake_128Hash[200];
} shake_128_context_t;
```

```
typedef struct {
        uint64_t runningLengthHigh;
        uint64_t runningLengthLow;
        unsigned int output_length;
        unsigned char shake_256Hash[200];
} shake_256_context_t;
```

```
typedef struct {
        unsigned int major_version;
        unsigned int minor_version;
        unsigned int fixpack_version;
} libica_version_info;
```

## Return codes

The current libica functions use the standard Linux return codes listed in this topic.

**0**
Success

**EFAULT**
The message authentication (for GCM) or the signature verification (for ECDSA), or the RSA key generation (via OpenSSL) failed.

**EINVAL**
Incorrect parameter

**EIO**
I/O error

**EPERM**
Operation not permitted by hardware or software restrictions.

**ENODEV**
No such device

**ENOMEM**
Not enough memory

**errno**
When libica calls **open**, **close**, **begin_sigill_section**, the error codes of these programs are returned.

# Chapter 5. libica tools

The libica packages include tools to investigate the capabilities of your cryptographic hardware and how these capabilities are used by applications that use libica.

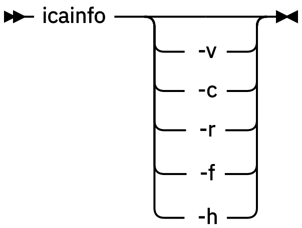
## icainfo - Show available libica functions

Use the **`icainfo`** command to find out which libica functions are available on your Linux system.

The **`icainfo`** output also indicates, whether the libica library has built-in FIPS support, whether it is running in FIPS mode, and whether it is in an error state. Algorithms that are not FIPS approved are marked as `blocked` in both table columns and cannot be processed when running in FIPS mode. All algorithms are marked as `blocked` when libica is in an error state.

### Format

**icainfo syntax**



Where:

**-v or --version**
Displays the version number of **`icainfo`**, and additionally displays optional vendor-specific libica build information.

**-c or --list-curves**
Displays the supported curves for elliptic curve cryptography. See also "Elliptic curve cryptography (ECC) functions" on page 45.

**-r or --list-rsa**
Displays the supported minimum and maximum RSA key lengths (for an example, see "Using RSA in FIPS mode" on page 44). When not running in FIPS mode, libica allows RSA keys of 57 bits up to 4096 bits. The lower limit depends on the distribution and the used OpenSSL version. The upper limit is imposed by the cryptographic coprocessors.

**-f or --list-fips-exceptions**
Display available algorithms that are non-approved.

**-h or --help**
Displays help information for the command.

To obtain an overview of the supported algorithms with modes of operations and how they are implemented on your Linux system (hardware, software, or both), enter:

```
# icainfo
```

View a sample output produced by this command. Available hardware support is presented in two columns: **hardware - dynamic** means support by cryptographic coprocessors, **hardware - static** means support by CPACF, with the current MSA level indicated. A `'no'` in column **software** indicates, that for this function no software fallback provided by OpenSSL is implemented in libica. A dash `'-'` in column **software** indicates, that libica is built without software fallbacks.

```
              Cryptographic algorithm support
------------------------------------------------------
               |         hardware        |
 function      |   dynamic  |   static   |  software
               |            |  (msa=09)  |
---------------+------------+------------+------------
         SHA-1 |     no     |    yes     |      -
       SHA-224 |     no     |    yes     |      -
           ...
       SHA-512 |     no     |    yes     |      -
   SHA-512/224 |     no     |    yes     |      -
   SHA-512/256 |     no     |    yes     |      -
           ...
      SHA3-512 |     no     |    yes     |      -
           ...
     SHAKE-256 |     no     |    yes     |      -
         GHASH |     no     |    yes     |      -
         P_RNG |  blocked   |  blocked   |  blocked
  DRBG-SHA-512 |     no     |    yes     |      -
          ECDH |     no     |    yes     |      -   /* ECDH+ECDSA only w. CPACF in FIPS mode
    ECDSA Sign |     no     |    yes     |      -
  ECDSA Verify |     no     |    yes     |      -
     EC Keygen |     no     |     no     |    yes   /* EC keygen: FIPS mode only in SW fallback
Ed25519 Keygen |  blocked   |  blocked   |  blocked /* all ED/X curves blocked in FIPS mode
  Ed25519 Sign |  blocked   |  blocked   |  blocked
Ed25519 Verify |  blocked   |  blocked   |  blocked
           ...
 X25519 Keygen |  blocked   |  blocked   |  blocked
 X25519 Derive |  blocked   |  blocked   |  blocked
   X448 Keygen |  blocked   |  blocked   |  blocked
   X448 Derive |  blocked   |  blocked   |  blocked
 RSA Keygen ME |     no     |     no     |    yes
RSA Keygen CRT |     no     |     no     |    yes
        RSA ME |    yes     |     no     |      -
       RSA CRT |    yes     |     no     |      -
       DES ECB |  blocked   |  blocked   |  blocked
       DES CBC |  blocked   |  blocked   |  blocked
           ...
      3DES ECB |  blocked   |  blocked   |  blocked  /* 3DES blocked in FIPS mode
      3DES CBC |  blocked   |  blocked   |  blocked
           ...
       AES ECB |     no     |    yes     |      -
           ...
       AES GCM |     no     |    yes     |      -
------------------------------------------------------
Built-in FIPS support: FIPS 140-3 mode active.
Software fallbacks are disabled.
```

The variant of the `libica.so` module, called `libica-cex.so`, introduced in “Using the libica-cex variant” on page 6 provides a corresponding **`icainfo-cex`** command to display the available functions of the `libica-cex` module.

The **`icainfo-cex`** command has the same syntax as **`icainfo`** (see “icainfo syntax” on page 139).

See an excerpt from an `icainfo-cex` output produced when running with the `libica-cex` module. The minus-sign - indicates the disabled features:

```
              Cryptographic algorithm support
------------------------------------------------------
               |         hardware         |
 function      |   dynamic  |   static    |  software
---------------+------------+-------------+-----------
         SHA-1 |      no    |      -      |      -
       SHA-224 |      no    |      -      |      -
       SHA-256 |      no    |      -      |      -
           ...
          ECDH |     yes    |      -      |      -
    ECDSA Sign |     yes    |      -      |      -
  ECDSA Verify |     yes    |      -      |      -
     EC Keygen |     yes    |      -      |      -
Ed25519 Keygen |      no    |      -      |      -
  Ed25519 Sign |      no    |      -      |      -
           ...
        RSA ME |     yes    |      -      |      -
       RSA CRT |     yes    |      -      |      -
       DES ECB |      no    |      -      |      -
       DES CBC |      no    |      -      |      -
           ...
------------------------------------------------------
No built-in FIPS support.
Software fallbacks are disabled in libica-cex.
CPACF support (including fallbacks) is disabled in libica-cex.
```

## icainfo -c

Use the **icainfo -c** command to list the elliptic curves that are supported by libica on your current system configuration. The availability of curves is, for example, dependent from the installed MSA level, whether cryptographic coprocessors in CCA mode are available, whether OpenSSL is in FIPS mode, or whether the whole system is in FIPS mode.

The table columns show whether a curve is supported by the hardware, either on a cryptographic coprocessor in CCA mode (**dynamic**), on CPACF (**static**), or with a **software** fallback by OpenSSL.

```
# icainfo -c

-------------------------------------------------------
                 |         hardware          |
        EC curve |   dynamic  |   static     |  software
                 |            |  (msa=09)    |
-----------------+------------+--------------+-----------
      prime192v1 |    yes     |     no       |    yes
       secp224r1 |    yes     |     no       |    yes
      prime256v1 |    yes     |    yes       |    yes
       secp384r1 |    yes     |    yes       |    yes
       secp521r1 |    yes     |    yes       |    yes
 brainpoolP160r1 |    yes     |     no       |    yes
 brainpoolP192r1 |    yes     |     no       |    yes
 brainpoolP224r1 |    yes     |     no       |    yes
 brainpoolP256r1 |    yes     |     no       |    yes
 brainpoolP320r1 |    yes     |     no       |    yes
 brainpoolP384r1 |    yes     |     no       |    yes
 brainpoolP512r1 |    yes     |     no       |    yes
         ED25519 |     no     |    yes       |     no
           ED448 |     no     |    yes       |     no
          X25519 |     no     |    yes       |     no
            X448 |     no     |    yes       |     no
-------------------------------------------------------
No built-in FIPS support.
```

Curves may or may not be supported because of the following reasons:

- The curve requires MSA9 (IBM z15 or later).
- A CCA coprocessor is available.
- The curve is not supported by OpenSSL in FIPS mode.

## icainfo -f

Use the **icainfo -f** command to list non-approved, but still available functions in FIPS mode.

```
# icainfo -f

              FIPS service indicator
------------------------------------------------------
               |      Available but non-approved
function       |   dynamic  |   static   |  software
---------------+--------------------------------------
  DRBG-SHA-512 |      -     |    yes     |      -
        RSA ME |    yes     |     -      |      -
       RSA CRT |    yes     |     -      |      -
------------------------------------------------------
```

The output displays algorithms or libica mechanisms that are considered to be not FIPS-compliant, but are not blocked. Applications may then decide whether to use an algorithm or mechanism or not. All algorithms or mechanisms that are not displayed, are either FIPS-compliant or shown as blocked in the default **icainfo** output (without a parameter). Applications can obtain a FIPS service indicator list using the "ica_get_fips_indicator" on page 117 function. This list indicates for each function whether it is approved (FIPS-compliant), non-approved, or non-approved but still available through an exception.

# icastats - Show use of libica functions

Use the **icastats** utility to find out whether libica uses hardware acceleration features or works with software fallbacks. **icastats** collects the statistical data per user and not per system.

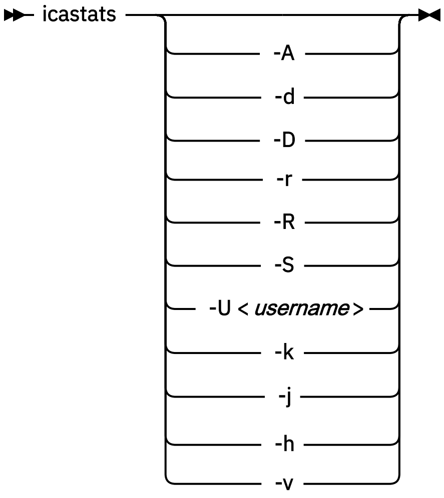
The command also shows which specific functions of libica are used. For a standard user, **icastats** shows a statistics table with all crypto operations that are used by the user's processes. For the root user, **icastats** provides statistics for all users, or processes, on the system.

The shared memory segment that holds the statistic data is created when a user starts **icastats** or when a program is started, that performs cryptographic operations using libica. Once the shared memory segment exists, it can only be removed by one of the delete options (**-d** or **-D**) provided with the **icastats** utility. Thus, this function collects crypto statistics independently from the process context for continuing availability of data. All cryptographic operations using libica are counted into the statistics.

**Note:** Before deleting the shared memory segment, ensure that there are no running applications that are using this memory segment.

## Format

**icastats syntax**



Where:

**-A or --all**
Shows the statistic tables from all users (for root users only).

**-d or --delete**
Removes the user specific shared memory segment.

**-D or --delete-all**
Removes all shared memory segments (for root users only).

**-r or --reset**
Resets the user statistic data table.

**-R or --reset-all**
Resets all statistic data tables from all users (for root users only).

**-S or --summary**
Shows accumulated statistics from all users (for root users only).

**-U <username> or --user <username>**
Shows statistic data for a dedicated user (for root users only).

**-k or --key-sizes**
Displays the per-key-size counters for the usage of AES, RSA and ECC algorithms.

For AES algorithms, separate counters exist for key sizes of 128, 192 and 256 bits.

For RSA algorithms, separate counters exist for RSA keys of 512, 1024, 2048, and 4096 bits. RSA key sizes below 512 bits are counted as 512 bits. RSA key sizes in between the counted key sizes, are counted as the next smaller one (for example, 3072 bits is counted as 2048 bits). RSA key sizes higher than 4096 bits are counted as 4096 bits.

For ECC algorithms, separate counters exist for key sizes of 160, 192, 224, 256, 320, 384, 512, and 521 bits. This maps to the curves supported by libica.

If omitted, per default, only the overall usage of the algorithms are displayed.

**-j or --json**
Produces a machine readable JSON output format to enable automatic processing of libica statistics.

**-h or --help**
Displays help information for the command.

**-v or --version**
Displays the version number of **`icastats`**, then exits.

### Examples

To display the current use of libica functions issue: **`icastats`**

```
# icastats


 function     |          # hardware      |       # software
--------------+--------------------------+-------------------------
              |       ENC    CRYPT   DEC |        ENC    CRYPT   DEC
--------------+--------------------------+-------------------------
        SHA-1 |               0          |                0
      SHA-224 |               0          |                0
          ...
     SHA3-384 |             507          |                0
          ...
    SHAKE-256 |            8276          |                0
          ...
        P_RNG |              55          |                0
 DRBG-SHA-512 |           29400          |                0
         ECDH |            4188          |                0
   ECDSA Sign |            1480          |                0
 ECDSA Verify |            1480          |                0
    EC Keygen |             132          |                0
       RSA-ME |             351          |                1
      RSA-CRT |              64          |                0
      DES ECB |         0              0 |         0             0
      DES CBC |         0              0 |         0             0
          ...
     AES CMAC |         0              0 |         0             0
      AES XTS |         0              0 |         0             0
      AES GCM |         0              0 |         0             0
```

To display the current use of libica functions, broken down to key sizes, issue: **`icastats --key-sizes`**

```
# icastats --key-sizes

 function       |             hardware         |              software
----------------+------------------------------+-----------------------------
                |        ENC    CRYPT     DEC  |        ENC     CRYPT    DEC
----------------+------------------------------+-----------------------------
          SHA-1 |                  81          |                    0
        SHA-224 |                  39          |                    0
        SHA-256 |                  43          |                    0
        SHA-384 |                 507          |                    0
        SHA-512 |                  13          |                    0
            ...
      SHAKE-128 |                   0          |                    0
      SHAKE-256 |                8276          |                    0
            ...
            ...
          P_RNG |                  55          |                    0
   DRBG-SHA-512 |                 168          |                    0
           ECDH |                   0          |                    0
          - 160 |                   0          |                    0
          - 192 |                   0          |                    0
            ...
            ...
      EC Keygen |                   0          |                    0
          - 160 |                   0          |                    0
          - 192 |                   0          |                    0
          - 224 |                   0          |                    0
            ...
         RSA-ME |                2799          |                    0
          - 512 |                   0          |                    0
         - 1024 |                 392          |                    0
         - 2048 |                1607          |                    0
         - 4096 |                 800          |                    0
        RSA-CRT |                  64          |                    0
          - 512 |                   0          |                    0
         - 1024 |                   0          |                    0
         - 2048 |                  12          |                    0
         - 4096 |                  52          |                    0
        AES ECB |           0                0 |           0               0
          - 128 |           0                0 |           0               0
            ...
        AES GCM |           0                0 |           0               0
          - 128 |           0                0 |           0               0
            ...
```

### Example of a JSON output

```
 icastats --key-sizes --j

        "host": {
                "nodename": "system1.lnxne.boe",
                "sysname": "Linux",
                "release": "5.14.0-20210817.rc6.git0.8cdcf75aa9ff.300.fc34.s390x",
                "machine": "s390x",
                "date": "2022-03-10T15:45:02Z"
        },
        "users": [
                {
                        "user": "root",
                        "functions": [
                                {
                                        "function": "SHA-1",
                                        "hw-crypt": 81,
                                        "sw-crypt": 0
                                },
                                {
                                        "function": "SHA-224",
                                        "hw-crypt": 39,
                                        "sw-crypt": 0
                                },
                            ...
                            ...
                            ...
                                {
                                        "function": "DRBG-SHA-512",
                                        "hw-crypt": 168,
                                        "sw-crypt": 0
                                },
                                {
                                        "function": "ECDH - 160",
                                        "hw-crypt": 0,
                                        "sw-crypt": 0
                                },
                            ...
                            ...
                            ...
                                {
                                        "function": "RSA-ME - 512",
                                        "hw-crypt": 0,
                                        "sw-crypt": 0
                                },
                                {
                                        "function": "RSA-ME - 1024",
                                        "hw-crypt": 392,
                                        "sw-crypt": 0
                                },
                             ...
                             ...
                             ...
                                {
                                        "function": "AES ECB - 128",
                                        "hw-enc": 0,
                                        "sw-enc": 0,
                                        "hw-dec": 0,
                                        "sw-dec": 0
                                },

                        ]
                }
        ]
}
```

**ENC**
is shown for a two way function performing encryption.

**CRYPT**
indicates cryptographic functions that produce a one-way result on given data, for example, creating a digital hash value from a given input text, or creating/verifying a digital signature.

**DEC**
is shown for a two way function performing decryption.

Note that one single libica function may increase several different counters when internally using different hardware functions. For example, performing AES GCM on a z13 involves using the AES ECB, AES CTR and GHASH hardware functions. On a z14, the AES GCM counter increases to indicate the use of the KMA instruction. Depending on the input data, other counters may also increase. Therefore, by looking at the hardware counters, it is not possible to see how often a particular API function was called.

## Logging and error handling

Access failures to the shared memory segments that are used by the **icastats** utility, are logged once via the syslog interface. After a failed attempt to access the shared memory segment, the library no longer collects any statistic data for this application (related to application lifetime and user).

**Example** of syslog message:

```
<date> <machine> <application>: failed to create or access shared memory segment.
```

The **icastats** utility prints an error message if it cannot create, access, or remove the shared memory segment.

**Note:** The log message may indicate a permission problem with the shared memory segment. An administrator can remove the defect memory segment. The next call of **icastats** should create a new memory segment automatically.

You can view the shared memory segments and information about creators and owners with an **ipcs** command, for example:

```
ipcs -i ID
ipcs -m
```

# Chapter 6. Examples

These sample program segments illustrate the use of the libica APIs.

These examples are released under the Common Public License - V1.0, which is stated in full at the end of this chapter. See "Common Public License - V1.0" on page 192.

In the extracted source package, you also find test cases for all APIs in directory `.../test/`. For information on how to compile the test cases, refer to the INSTALL file from the libica package.

View a list of examples for libica, and the makefile used to create the library.

- "SHAKE-128 example" on page 149
- "SHA-256 example" on page 151
- "RSA example" on page 153
- "AES with CFB mode example" on page 156
- "AES with CTR mode example" on page 166
- "AES with OFB mode example" on page 174
- "AES with XTS mode example" on page 180
- "CMAC example" on page 187
- "ECDSA example" on page 190
- "ECDH example" on page 191
- "Makefile example" on page 192
- "Common Public License - V1.0" on page 192

## SHAKE-128 example

```
/* This program is released under the Common Public License V1.0
 *
 * You should have received a copy of Common Public License V1.0 along with
 * with this program.
 *
 * Copyright IBM Corp. 2017
 *
 */
#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include <errno.h>
#include <ica_api.h>

/* The name of the file to calculate the SHAKE-128 hash from */
#define FILE_NAME "example_shake_128.c"

/* Size of the chunks in which the file is read.
 * Must be a multiple of 168 bytes (the SHAKE-128 block size).
 */
#define CHUNK_SIZE 168

/* An arbitrary output_length in case the user did not specify a value via args */
#define SAMPLE_SHAKE_OUTPUT_LENGTH 123

/* Prints hex values to standard out. */
static void dump_data(unsigned char *data, unsigned long length);

/* Prints a description of the return value to standard out. */
static int handle_ica_error(int rc);

int main( int argc, char **argv)
{
    int rc=0;
    unsigned int output_length = SAMPLE_SHAKE_OUTPUT_LENGTH;
    /* Try to read the user specified output length. If none given, use our
     * sample value.
     */
    if (argc > 1 && argv[1] != NULL)
        output_length = atoi(argv[1]);

    /* This is the buffer where the SHAKE-128 hash is generated into.
     * The SHAKE algorithm can create output of any length greater or equal
     * to 8 bytes. Let's use an output length of 256 bytes for this example.
     */
    unsigned char* shake_result_p;

    /* The file will be read in several chunks into this buffer.
     * The chunks will be the input to the ica_shake_128 function which
     * we call for each chunk.
     */
    unsigned char shake_input[CHUNK_SIZE];

    /* This is the SHAKE-128 context. It stores intermediate values
     * needed when chaining multiple chunks (as we do).
     */
    shake_128_context_t context;

    /* Open the file in binary mode and read its content in chunks */
    FILE *f;
    f = fopen(FILE_NAME, "r");
    if (f == NULL)
        return handle_ica_error(errno);

    /* Allocate a buffer for the output value */
    shake_result_p = malloc(output_length);
    if (shake_result_p == NULL) {
        printf("Cannot malloc %d bytes for output value. \n", output_length);
        return EINVAL;
    }

    /* Perform the shake-128 operation ... */
    int len;
    unsigned long total_size = 0;
    memset((char*)&context, 0, sizeof(context));
    while (!feof(f)) {
        /* read a chunk of data */
        len = fread(shake_input, 1, CHUNK_SIZE, f);
        if (total_size == 0) {
            /* this is the first chunk */
            rc = ica_shake_128(SHA_MSG_PART_FIRST, len, shake_input,
                    &context, shake_result_p, output_length);
        } else if (!feof(f)) {
            /* add this chunk to the hash */
            rc = ica_shake_128(SHA_MSG_PART_MIDDLE, len, shake_input,
                    &context, shake_result_p, output_length);
        } else {
            /* this is the last chunk */
            rc = ica_shake_128(SHA_MSG_PART_FINAL, len, shake_input,
                    &context, shake_result_p, output_length);
        }

        total_size += len;
        if (rc)
            break;
    }

    /* close the file */
    fclose(f);

    /* Error handling (if necessary). */
    if (rc)
        return handle_ica_error(rc);

    /* Dump the generated hash to standard output, just for
     * a visual control.
     */
    printf("SHAKE-128 hash with %d bytes of file '%s' (%lu bytes):\n", output_length,
            FILE_NAME, total_size);

    dump_data(shake_result_p, output_length);
}

static void dump_data(unsigned char *data, unsigned long length)
{
    unsigned char *ptr;
    int i;
    for (ptr = data, i = 1; ptr < (data + length); ptr++, i++) {
        printf("0x%02x ", *ptr);
        if ((i % 16) == 0)
            printf("\n");
    }
    if (i % 16)
        printf("\n");
}

static int handle_ica_error(int rc)
{
    switch (rc) {
    case 0:
        printf("OK\n");
        break;
    case EINVAL:
        printf("Incorrect parameter.\n");
        break;
    case EPERM:
        printf("Operation not permitted by Hardware (CPACF).\n");
        break;
    case EIO:
        printf("I/O error.\n");
        break;
    default:
        printf("unknown error.\n");
    }
    return rc;
}
```

## SHA-256 example

```
/* This program is released under the Common Public License V1.0
 *
 * You should have received a copy of Common Public License V1.0 along with
 * with this program.
 *
 * Copyright IBM Corp. 2016
 *
 */

#include <stdio.h>
#include <string.h>
#include <errno.h>

#include <ica_api.h>

/* The name of the file to calcualte the SHA256 hash from */
#define FILE_NAME     "example_sha256.c"

/* Size of the chunks in which the file is read.
 * Must be a multiple of 64 bytes.
 */
#define CHUNK_SIZE    1024

/* Prints hex values to standard out. */
static void dump_data(unsigned char *data, unsigned long length);
/* Prints a description of the return value to standard out. */
static int handle_ica_error(int rc);

int main(char **argv, int argc)
{
    int rc;

    /* This is the buffer where the SHA256 hash is generated into.
     * For SHA256, it needs to be 32 bytes in size (SHA256_HASH_LENGTH).
     */
    unsigned char sha_result[SHA256_HASH_LENGTH];

    /* The file will be read in several chunks into this buffer.
     * The chunks will be the input to the ica_sha256 function which
     * we call for each chunk.
     */
    unsigned char sha_input[CHUNK_SIZE];

    /* This is the SHA 256 context. It stores intermediate values
     * needed when chaining multiple chunks (as we do).
     */
    sha256_context_t context;

    /* Open the file in binary mode and read its content in chunks */
    FILE *f;

    f = fopen(FILE_NAME,"r");
    if (f==NULL)
        return handle_ica_error(errno);

    int len;
    unsigned long total_size = 0;

    while(!feof(f)) {
        /* read a chunk of data */
        len = fread(sha_input, 1, CHUNK_SIZE, f);

        if (total_size == 0) {
            /* this is the first chunk */
            rc = ica_sha256(SHA_MSG_PART_FIRST,
                        len, sha_input,
                        &context,
                        sha_result);
        }
        else if (!feof(f)) {
            /* add this chunk to the hash */
            rc = ica_sha256(SHA_MSG_PART_MIDDLE,
                        len, sha_input,
                        &context,
                        sha_result);
        }
        else  {
            /* this is the last chunk */
            rc = ica_sha256(SHA_MSG_PART_FINAL,
                        len, sha_input,
                        &context,
                        sha_result);
        }

        total_size += len;

        if (rc)
            break;
    }

    /* close the file */
    fclose(f);

    /* Error handling (if necessary). */
    if (rc)
        return handle_ica_error(rc);

    /* Dump the generated hash to standard output, just for
     * a visual control.
     *
     * Note: You can verify the displayed hash using command
     *       'sha256sum example_sha256.c'
     */
    printf("SHA256 hash of file '%s' (%u bytes):\n", FILE_NAME, total_size);
    dump_data(sha_result, sizeof(sha_result));
}

static void dump_data(unsigned char *data, unsigned long length)
{
    unsigned char *ptr;
    int i;

    for (ptr = data, i = 1; ptr < (data+length); ptr++, i++) {
        printf("0x%02x ", *ptr);
        if ((i % 16) == 0)
            printf("\n");
    }
    if (i % 16)
        printf("\n");
}

static int handle_ica_error(int rc)
{
    switch (rc) {
    case 0:
        printf("OK\n");
        break;
    case EINVAL:
        printf("Incorrect parameter.\n");
        break;
    case EPERM:
        printf("Operation not permitted by Hardware (CPACF).\n");
        break;
    case EIO:
        printf("I/O error.\n");
        break;
    default:
        printf("unknown error.\n");
    }

    return rc;
}
```

## RSA example

```
/* This program is released under the Common Public License V1.0
 *
 * You should have received a copy of Common Public License V1.0 along with
 * with this program.
 *
 * Copyright IBM Corp. 2016
 *
 */

#include <stdio.h>
#include <string.h>
#include <errno.h>

#include <ica_api.h>

#define RSA_KEY_SIZE_BITS   2048
#define RSA_KEY_SIZE_BYTES  (RSA_KEY_SIZE_BITS + 7) / 8

#define RSA_DATA_SIZE_BYTES RSA_KEY_SIZE_BYTES

/* This is the plain data, you want to encrypt. For the
 * encryption mode used in this example, it is necessary,
 * that the length of the encrypted data is less or eqal
 * to the RSA key length in bytes.
 */
unsigned char message[] = {
    0x55, 0x73, 0x69, 0x6e, 0x67, 0x20, 0x6c, 0x69,
    0x62, 0x69, 0x63, 0x61, 0x20, 0x69, 0x73, 0x20,
    0x73, 0x6d, 0x61, 0x72, 0x74, 0x20, 0x61, 0x6e,
    0x64, 0x20, 0x65, 0x61, 0x73, 0x79, 0x21, 0x00,
};

/* Prints hex values to standard out. */
static void dump_data(unsigned char *data, unsigned long length);
/* Prints a description of the return value to standard out. */
static int handle_ica_error(int rc);

int main(char **argv, int argc)
{
    int rc;

    /* This is the RSA public/private key pair. We use libica function
     * ica_rsa_key_generate_crt to generate it.
     */
    ica_rsa_key_mod_expo_t public_key;
    ica_rsa_key_crt_t private_key;
    unsigned char public_modulus[RSA_KEY_SIZE_BYTES];
    unsigned char public_exponent[RSA_KEY_SIZE_BYTES];
    unsigned char private_p[RSA_KEY_SIZE_BYTES];
    unsigned char private_q[RSA_KEY_SIZE_BYTES];
    unsigned char private_dp[RSA_KEY_SIZE_BYTES];
    unsigned char private_dq[RSA_KEY_SIZE_BYTES];
    unsigned char private_qInverse[RSA_KEY_SIZE_BYTES];

    unsigned char plain_data[RSA_DATA_SIZE_BYTES];
    unsigned char cipher_data[RSA_DATA_SIZE_BYTES];
    unsigned char decrypt_data[RSA_DATA_SIZE_BYTES];

    /* This is the adapter handle */
    ica_adapter_handle_t handle;
    /* Open the adapter */
    rc = ica_open_adapter(&handle);

    /* Error handling (if necessary). */
    if (rc)
        return handle_ica_error(rc);
    if (handle == DRIVER_NOT_LOADED)
        return handle_ica_error(-1);

    /* Setup the public_key and private_key structures */
    public_key.key_length  = RSA_KEY_SIZE_BYTES;
    public_key.modulus     = public_modulus;
    public_key.exponent    = public_exponent;
    private_key.key_length = RSA_KEY_SIZE_BYTES;
    private_key.p          = private_p;
    private_key.q          = private_q;
    private_key.dp         = private_dp;
    private_key.dq         = private_dq;
    private_key.qInverse   = private_qInverse;

    /* Zero the key fields
       Note: If the exponent element in the public key is not set,
             (i.e. all zero) it is randomly generated.*/
    memset(public_modulus, 0, sizeof(public_modulus));
    memset(public_exponent, 0, sizeof(public_exponent));
    memset(private_p, 0, sizeof(private_p));
    memset(private_q, 0, sizeof(private_q));
    memset(private_dp, 0, sizeof(private_dp));
    memset(private_dq, 0, sizeof(private_dq));
    memset(private_qInverse, 0, sizeof(private_qInverse));

    /* Generate a key for RSA */
    rc = ica_rsa_key_generate_crt(handle,
                        RSA_KEY_SIZE_BITS,
                        &public_key, &private_key);

    /* Error handling (if necessary). */
    if (rc)
        return handle_ica_error(rc);

    printf("Public modulus:\n");
    dump_data(public_modulus, sizeof(public_modulus));
    printf("Public exponent:\n");
    dump_data(public_exponent, sizeof(public_exponent));
    printf("Private p:\n");
    dump_data(private_p, sizeof(private_p));
    printf("Private q:\n");
    dump_data(private_q, sizeof(private_q));
    printf("Private dp:\n");
    dump_data(private_dp, sizeof(private_dp));
    printf("Private dq:\n");
    dump_data(private_dq, sizeof(private_dq));
    printf("Private qInverse:\n");
    dump_data(private_qInverse, sizeof(private_qInverse));

    /* Left allign the message data into the plain_data buffer
     * and padd it to the right with zeros.
     * Note: In real life you would perform propper padding of
     * the data. In this example we simply left pad the data
     * with binary zeros.
     */
    memset(plain_data, 0, sizeof(plain_data));
    memcpy(plain_data + sizeof(plain_data)-sizeof(message),
            message, sizeof(message));

    /* Dump plain data to standard output, just for
     * a visual control.
     */
    printf("plain data:\n");
    dump_data(plain_data, sizeof(plain_data));

    /* Encrypt the plain data to cipher data, using the public key. */
    rc = ica_rsa_mod_expo(handle, plain_data,
                        &public_key, cipher_data);

    /* Error handling (if necessary). */
    if (rc)
        return handle_ica_error(rc);

    /* Dump encrypted data. */
    printf("encrypted data:\n");
    dump_data(cipher_data, sizeof(plain_data));
    /* Decrypt cipher data to dercrypt data, using the private key. */
    rc = ica_rsa_crt(handle, cipher_data,
                    &private_key, decrypt_data);

    /* Error handling (if necessary). */
    if (rc)
        return handle_ica_error(rc);

    /* Dump decrypted data.
     * Note: Please compare output with the plain data, they are the same.
     */
    printf("decrypted data:\n");
    dump_data(decrypt_data, sizeof(plain_data));

    /* In our example, the data is right alligned in the buffer, padded with
     * zeros to the left. Find first non zero byte which is the start of the
     * original data.
     * Note: In real life the data would be properly padded and thus would
     * have to be unpadded first.
     */
    unsigned char *c;
    for(c=decrypt_data;
        c<decrypt_data+sizeof(plain_data) && *c==0x00;
        c++);

    /* Surprise... :-)
     * Note: The following will only work in this example!
     */
    printf("%s\n", c);

    /* Close the adapter */
    rc = ica_close_adapter(handle);

    /* Error handling (if necessary). */
    if (rc)
        return handle_ica_error(rc);
}

static void dump_data(unsigned char *data, unsigned long length)
{
    unsigned char *ptr;
    int i;

    for (ptr = data, i = 1; ptr < (data+length); ptr++, i++) {
        printf("0x%02x ", *ptr);
        if ((i % 16) == 0)
            printf("\n");
    }
    if (i % 16)
        printf("\n");
}

static int handle_ica_error(int rc)
{
    switch (rc) {
    case 0:
        printf("OK\n");
        break;
    case EINVAL:
        printf("Incorrect parameter.\n");
        break;
    case EPERM:
        printf("Operation not permitted by Hardware (CPACF).\n");
        break;
    case EIO:
        printf("I/O error.\n");
        break;
    case -1:
        printf("Driver not loaded\n");
        break;
    default:
        printf("unknown error.\n");
    }

    return rc;
}
```

# AES with CFB mode example

```
/* This program is released under the Common Public License V1.0
 *
 * You should have received a copy of Common Public License V1.0 along with
 * with this program.
 */

/* Copyright IBM Corp. 2010, 2011 */
#include <fcntl.h>
#include <sys/errno.h>
#include <stdio.h>
#include <string.h>
#include <strings.h>
#include <stdlib.h>
#include "ica_api.h"

#define NR_TESTS 12
#define NR_RANDOM_TESTS 1000

/* CFB128 data -1- AES128 */
unsigned char NIST_KEY_CFB_E1[] = {
    0x2b, 0x7e, 0x15, 0x16, 0x28, 0xae, 0xd2, 0xa6,
    0xab, 0xf7, 0x15, 0x88, 0x09, 0xcf, 0x4f, 0x3c,
};

unsigned char NIST_IV_CFB_E1[] = {
    0x00, 0x01, 0x02, 0x03, 0x04, 0x05, 0x06, 0x07,
    0x08, 0x09, 0x0a, 0x0b, 0x0c, 0x0d, 0x0e, 0x0f,
};

unsigned char NIST_EXPECTED_IV_CFB_E1[] = {
    0x3b, 0x3f, 0xd9, 0x2e, 0xb7, 0x2d, 0xad, 0x20,
    0x33, 0x34, 0x49, 0xf8, 0xe8, 0x3c, 0xfb, 0x4a,
};

unsigned char NIST_TEST_DATA_CFB_E1[] = {
    0x6b, 0xc1, 0xbe, 0xe2, 0x2e, 0x40, 0x9f, 0x96,
    0xe9, 0x3d, 0x7e, 0x11, 0x73, 0x93, 0x17, 0x2a,
};

unsigned char NIST_TEST_RESULT_CFB_E1[] = {
    0x3b, 0x3f, 0xd9, 0x2e, 0xb7, 0x2d, 0xad, 0x20,
    0x33, 0x34, 0x49, 0xf8, 0xe8, 0x3c, 0xfb, 0x4a,
};

unsigned int NIST_LCFB_E1 = 128 / 8;

/* CFB128 data -2- AES128 */
unsigned char NIST_KEY_CFB_E2[] = {
    0x2b, 0x7e, 0x15, 0x16, 0x28, 0xae, 0xd2, 0xa6,
    0xab, 0xf7, 0x15, 0x88, 0x09, 0xcf, 0x4f, 0x3c,
};

unsigned char NIST_IV_CFB_E2[] = {
    0x3b, 0x3f, 0xd9, 0x2e, 0xb7, 0x2d, 0xad, 0x20,
    0x33, 0x34, 0x49, 0xf8, 0xe8, 0x3c, 0xfb, 0x4a,
};

unsigned char NIST_EXPECTED_IV_CFB_E2[] = {
    0xc8, 0xa6, 0x45, 0x37, 0xa0, 0xb3, 0xa9, 0x3f,
    0xcd, 0xe3, 0xcd, 0xad, 0x9f, 0x1c, 0xe5, 0x8b,
};

unsigned char NIST_TEST_DATA_CFB_E2[] = {
    0xae, 0x2d, 0x8a, 0x57, 0x1e, 0x03, 0xac, 0x9c,
    0x9e, 0xb7, 0x6f, 0xac, 0x45, 0xaf, 0x8e, 0x51,
};

unsigned char NIST_TEST_RESULT_CFB_E2[] = {
    0xc8, 0xa6, 0x45, 0x37, 0xa0, 0xb3, 0xa9, 0x3f,
    0xcd, 0xe3, 0xcd, 0xad, 0x9f, 0x1c, 0xe5, 0x8b,
};

unsigned int NIST_LCFB_E2 = 128 / 8;

/* CFB8 data -3- AES128 */
unsigned char NIST_KEY_CFB_E3[] = {
    0x2b, 0x7e, 0x15, 0x16, 0x28, 0xae, 0xd2, 0xa6,
    0xab, 0xf7, 0x15, 0x88, 0x09, 0xcf, 0x4f, 0x3c,
};

unsigned char NIST_IV_CFB_E3[] = {
    0x00, 0x01, 0x02, 0x03, 0x04, 0x05, 0x06, 0x07,
    0x08, 0x09, 0x0a, 0x0b, 0x0c, 0x0d, 0x0e, 0x0f,
};

unsigned char NIST_EXPECTED_IV_CFB_E3[] = {
    0x01, 0x02, 0x03, 0x04, 0x05, 0x06, 0x07, 0x08,
    0x09, 0x0a, 0x0b, 0x0c, 0x0d, 0x0e, 0x0f, 0x3b,
};
unsigned char NIST_TEST_DATA_CFB_E3[] = {
    0x6b,
};

unsigned char NIST_TEST_RESULT_CFB_E3[] = {
    0x3b,
};
unsigned int NIST_LCFB_E3 = 8 / 8;

/* CFB8 data -4- AES128 */
unsigned char NIST_KEY_CFB_E4[] = {
    0x2b, 0x7e, 0x15, 0x16, 0x28, 0xae, 0xd2, 0xa6,
    0xab, 0xf7, 0x15, 0x88, 0x09, 0xcf, 0x4f, 0x3c,
};

unsigned char NIST_IV_CFB_E4[] = {
    0x01, 0x02, 0x03, 0x04, 0x05, 0x06, 0x07, 0x08,
    0x09, 0x0a, 0x0b, 0x0c, 0x0d, 0x0e, 0x0f, 0x3b,
};

unsigned char NIST_EXPECTED_IV_CFB_E4[] = {
    0x02, 0x03, 0x04, 0x05, 0x06, 0x07, 0x08, 0x09,
    0x0a, 0x0b, 0x0c, 0x0d, 0x0e, 0x0f, 0x3b, 0x79,
};
unsigned char NIST_TEST_DATA_CFB_E4[] = {
    0xc1,
};

unsigned char NIST_TEST_RESULT_CFB_E4[] = {
    0x79,
};

unsigned int NIST_LCFB_E4 = 8 / 8;


/* CFB 128 data -5- for AES192 */
unsigned char NIST_KEY_CFB_E5[] = {
    0x8e, 0x73, 0xb0, 0xf7, 0xda, 0x0e, 0x64, 0x52,
    0xc8, 0x10, 0xf3, 0x2b, 0x80, 0x90, 0x79, 0xe5,
    0x62, 0xf8, 0xea, 0xd2, 0x52, 0x2c, 0x6b, 0x7b,
};

unsigned char NIST_IV_CFB_E5[] = {
    0x00, 0x01, 0x02, 0x03, 0x04, 0x05, 0x06, 0x07,
    0x08, 0x09, 0x0a, 0x0b, 0x0c, 0x0d, 0x0e, 0x0f,
};

unsigned char NIST_EXPECTED_IV_CFB_E5[] = {
    0xcd, 0xc8, 0x0d, 0x6f, 0xdd, 0xf1, 0x8c, 0xab,
    0x34, 0xc2, 0x59, 0x09, 0xc9, 0x9a, 0x41, 0x74,
};

unsigned char NIST_TEST_DATA_CFB_E5[] = {
    0x6b, 0xc1, 0xbe, 0xe2, 0x2e, 0x40, 0x9f, 0x96,
    0xe9, 0x3d, 0x7e, 0x11, 0x73, 0x93, 0x17, 0x2a,
};

unsigned char NIST_TEST_RESULT_CFB_E5[] = {
    0xcd, 0xc8, 0x0d, 0x6f, 0xdd, 0xf1, 0x8c, 0xab,
    0x34, 0xc2, 0x59, 0x09, 0xc9, 0x9a, 0x41, 0x74,
};

unsigned int NIST_LCFB_E5 = 128 / 8;

/* CFB 128 data -6- for AES192 */
unsigned char NIST_KEY_CFB_E6[] = {
    0x8e, 0x73, 0xb0, 0xf7, 0xda, 0x0e, 0x64, 0x52,
    0xc8, 0x10, 0xf3, 0x2b, 0x80, 0x90, 0x79, 0xe5,
    0x62, 0xf8, 0xea, 0xd2, 0x52, 0x2c, 0x6b, 0x7b,
};
```

```
unsigned char NIST_IV_CFB_E6[] = {
    0xcd, 0xc8, 0x0d, 0x6f, 0xdd, 0xf1, 0x8c, 0xab,
    0x34, 0xc2, 0x59, 0x09, 0xc9, 0x9a, 0x41, 0x74,
};

unsigned char NIST_EXPECTED_IV_CFB_E6[] = {
    0x67, 0xce, 0x7f, 0x7f, 0x81, 0x17, 0x36, 0x21,
    0x96, 0x1a, 0x2b, 0x70, 0x17, 0x1d, 0x3d, 0x7a,
};

unsigned char NIST_TEST_DATA_CFB_E6[] = {
    0xae, 0x2d, 0x8a, 0x57, 0x1e, 0x03, 0xac, 0x9c,
    0x9e, 0xb7, 0x6f, 0xac, 0x45, 0xaf, 0x8e, 0x51,
};

unsigned char NIST_TEST_RESULT_CFB_E6[] = {
    0x67, 0xce, 0x7f, 0x7f, 0x81, 0x17, 0x36, 0x21,
    0x96, 0x1a, 0x2b, 0x70, 0x17, 0x1d, 0x3d, 0x7a,
};

unsigned int NIST_LCFB_E6 = 128 / 8;

/* CFB 128 data -7- for AES192 */
unsigned char NIST_KEY_CFB_E7[] = {
    0x8e, 0x73, 0xb0, 0xf7, 0xda, 0x0e, 0x64, 0x52,
    0xc8, 0x10, 0xf3, 0x2b, 0x80, 0x90, 0x79, 0xe5,
    0x62, 0xf8, 0xea, 0xd2, 0x52, 0x2c, 0x6b, 0x7b,
};

unsigned char NIST_IV_CFB_E7[] = {
    0x00, 0x01, 0x02, 0x03, 0x04, 0x05, 0x06, 0x07,
    0x08, 0x09, 0x0a, 0x0b, 0x0c, 0x0d, 0x0e, 0x0f,
};

unsigned char NIST_EXPECTED_IV_CFB_E7[] = {
    0x01, 0x02, 0x03, 0x04, 0x05, 0x06, 0x07, 0x08,
    0x09, 0x0a, 0x0b, 0x0c, 0x0d, 0x0e, 0x0f, 0xcd,
};

unsigned char NIST_TEST_DATA_CFB_E7[] = {
    0x6b,
};

unsigned char NIST_TEST_RESULT_CFB_E7[] = {
    0xcd,
};

unsigned int NIST_LCFB_E7 = 8 / 8;

/* CFB 128 data -8- for AES192 */
unsigned char NIST_KEY_CFB_E8[] = {
    0x8e, 0x73, 0xb0, 0xf7, 0xda, 0x0e, 0x64, 0x52,
    0xc8, 0x10, 0xf3, 0x2b, 0x80, 0x90, 0x79, 0xe5,
    0x62, 0xf8, 0xea, 0xd2, 0x52, 0x2c, 0x6b, 0x7b,
};

unsigned char NIST_IV_CFB_E8[] = {
    0x01, 0x02, 0x03, 0x04, 0x05, 0x06, 0x07, 0x08,
    0x09, 0x0a, 0x0b, 0x0c, 0x0d, 0x0e, 0x0f, 0xcd,
};

unsigned char NIST_EXPECTED_IV_CFB_E8[] = {
    0x02, 0x03, 0x04, 0x05, 0x06, 0x07, 0x08, 0x09,
    0x0a, 0x0b, 0x0c, 0x0d, 0x0e, 0x0f, 0xcd, 0xa2,
};

unsigned char NIST_TEST_DATA_CFB_E8[] = {
    0xc1,
};

unsigned char NIST_TEST_RESULT_CFB_E8[] = {
    0xa2,
};

unsigned int NIST_LCFB_E8 = 8 / 8;



/* CFB128 data -9- for AES256 */
unsigned char NIST_KEY_CFB_E9[] = {
    0x60, 0x3d, 0xeb, 0x10, 0x15, 0xca, 0x71, 0xbe,
    0x2b, 0x73, 0xae, 0xf0, 0x85, 0x7d, 0x77, 0x81,
    0x1f, 0x35, 0x2c, 0x07, 0x3b, 0x61, 0x08, 0xd7,
    0x2d, 0x98, 0x10, 0xa3, 0x09, 0x14, 0xdf, 0xf4,
};

unsigned char NIST_IV_CFB_E9[] = {
    0x00, 0x01, 0x02, 0x03, 0x04, 0x05, 0x06, 0x07,
    0x08, 0x09, 0x0a, 0x0b, 0x0c, 0x0d, 0x0e, 0x0f,
};

unsigned char NIST_EXPECTED_IV_CFB_E9[] = {
    0xdc, 0x7e, 0x84, 0xbf, 0xda, 0x79, 0x16, 0x4b,
    0x7e, 0xcd, 0x84, 0x86, 0x98, 0x5d, 0x38, 0x60,
};

unsigned char NIST_TEST_DATA_CFB_E9[] = {
    0x6b, 0xc1, 0xbe, 0xe2, 0x2e, 0x40, 0x9f, 0x96,
    0xe9, 0x3d, 0x7e, 0x11, 0x73, 0x93, 0x17, 0x2a,
};

unsigned char NIST_TEST_RESULT_CFB_E9[] = {
    0xdc, 0x7e, 0x84, 0xbf, 0xda, 0x79, 0x16, 0x4b,
    0x7e, 0xcd, 0x84, 0x86, 0x98, 0x5d, 0x38, 0x60,
};

unsigned int NIST_LCFB_E9 = 128 / 8;

/* CFB128 data -10- for AES256 */
unsigned char NIST_KEY_CFB_E10[] = {
    0x60, 0x3d, 0xeb, 0x10, 0x15, 0xca, 0x71, 0xbe,
    0x2b, 0x73, 0xae, 0xf0, 0x85, 0x7d, 0x77, 0x81,
    0x1f, 0x35, 0x2c, 0x07, 0x3b, 0x61, 0x08, 0xd7,
    0x2d, 0x98, 0x10, 0xa3, 0x09, 0x14, 0xdf, 0xf4,
};

unsigned char NIST_IV_CFB_E10[] = {
    0xdc, 0x7e, 0x84, 0xbf, 0xda, 0x79, 0x16, 0x4b,
    0x7e, 0xcd, 0x84, 0x86, 0x98, 0x5d, 0x38, 0x60,
};

unsigned char NIST_EXPECTED_IV_CFB_E10[] = {
    0x39, 0xff, 0xed, 0x14, 0x3b, 0x28, 0xb1, 0xc8,
    0x32, 0x11, 0x3c, 0x63, 0x31, 0xe5, 0x40, 0x7b,
};

unsigned char NIST_TEST_DATA_CFB_E10[] = {
    0xae, 0x2d, 0x8a, 0x57, 0x1e, 0x03, 0xac, 0x9c,
    0x9e, 0xb7, 0x6f, 0xac, 0x45, 0xaf, 0x8e, 0x51,
};

unsigned char NIST_TEST_RESULT_CFB_E10[] = {
    0x39, 0xff, 0xed, 0x14, 0x3b, 0x28, 0xb1, 0xc8,
    0x32, 0x11, 0x3c, 0x63, 0x31, 0xe5, 0x40, 0x7b,
};

unsigned int NIST_LCFB_E10 = 128 / 8;

/* CFB8 data -11- for AES256 */
unsigned char NIST_KEY_CFB_E11[] = {
    0x60, 0x3d, 0xeb, 0x10, 0x15, 0xca, 0x71, 0xbe,
    0x2b, 0x73, 0xae, 0xf0, 0x85, 0x7d, 0x77, 0x81,
    0x1f, 0x35, 0x2c, 0x07, 0x3b, 0x61, 0x08, 0xd7,
    0x2d, 0x98, 0x10, 0xa3, 0x09, 0x14, 0xdf, 0xf4,
};

unsigned char NIST_IV_CFB_E11[] = {
    0x00, 0x01, 0x02, 0x03, 0x04, 0x05, 0x06, 0x07,
    0x08, 0x09, 0x0a, 0x0b, 0x0c, 0x0d, 0x0e, 0x0f,
};

unsigned char NIST_EXPECTED_IV_CFB_E11[] = {
    0x01, 0x02, 0x03, 0x04, 0x05, 0x06, 0x07, 0x08,
    0x09, 0x0a, 0x0b, 0x0c, 0x0d, 0x0e, 0x0f, 0xdc,
};

unsigned char NIST_TEST_DATA_CFB_E11[] = {
    0x6b,
};

unsigned char NIST_TEST_RESULT_CFB_E11[] = {
    0xdc,
};
```

```
unsigned int NIST_LCFB_E11 = 8 / 8;

/* CFB8 data -12- for AES256 */
unsigned char NIST_KEY_CFB_E12[] = {
    0x60, 0x3d, 0xeb, 0x10, 0x15, 0xca, 0x71, 0xbe,
    0x2b, 0x73, 0xae, 0xf0, 0x85, 0x7d, 0x77, 0x81,
    0x1f, 0x35, 0x2c, 0x07, 0x3b, 0x61, 0x08, 0xd7,
    0x2d, 0x98, 0x10, 0xa3, 0x09, 0x14, 0xdf, 0xf4,
};

unsigned char NIST_IV_CFB_E12[] = {
    0x01, 0x02, 0x03, 0x04, 0x05, 0x06, 0x07, 0x08,
    0x09, 0x0a, 0x0b, 0x0c, 0x0d, 0x0e, 0x0f, 0xdc,
};

unsigned char NIST_EXPECTED_IV_CFB_E12[] = {
    0x02, 0x03, 0x04, 0x05, 0x06, 0x07, 0x08, 0x09,
    0x0a, 0x0b, 0x0c, 0x0d, 0x0e, 0x0f, 0xdc, 0x1f,
};

unsigned char NIST_TEST_DATA_CFB_E12[] = {
    0xc1,
};

unsigned char NIST_TEST_RESULT_CFB_E12[] = {
    0x1f,
};

unsigned int NIST_LCFB_E12 = 8 / 8;


void dump_array(unsigned char *ptr, unsigned int size)
{
    unsigned char *ptr_end;
    unsigned char *h;
    int i = 1;

    h = ptr;
    ptr_end = ptr + size;
    while (h < (unsigned char *)ptr_end) {
        printf("0x%02x ",(unsigned char ) *h);
        h++;
        if (i == 8) {
            printf("\n");
            i = 1;
        } else {
            ++i;
        }
    }
    printf("\n");
}

void dump_cfb_data(unsigned char *iv, unsigned int iv_length,
                   unsigned char *key, unsigned int key_length,
                   unsigned char *input_data, unsigned int data_length,
                   unsigned char *output_data)
{
    printf("IV \n");
    dump_array(iv, iv_length);
    printf("Key \n");
    dump_array(key, key_length);
    printf("Input Data\n");
    dump_array(input_data, data_length);
    printf("Output Data\n");
    dump_array(output_data, data_length);
}

void get_sizes(unsigned int *data_length, unsigned int *iv_length,
           unsigned int *key_length, unsigned int iteration)
{
    switch (iteration) {
        case 1:
            *data_length = sizeof(NIST_TEST_DATA_CFB_E1);
            *iv_length = sizeof(NIST_IV_CFB_E1);
            *key_length = sizeof(NIST_KEY_CFB_E1);
            break;
        case 2:
            *data_length = sizeof(NIST_TEST_DATA_CFB_E2);
            *iv_length = sizeof(NIST_IV_CFB_E2);
            *key_length = sizeof(NIST_KEY_CFB_E2);
            break;
        case 3:
            *data_length = sizeof(NIST_TEST_DATA_CFB_E3);
            *iv_length = sizeof(NIST_IV_CFB_E3);
            *key_length = sizeof(NIST_KEY_CFB_E3);
            break;
        case 4:
            *data_length = sizeof(NIST_TEST_DATA_CFB_E4);
            *iv_length = sizeof(NIST_IV_CFB_E4);
            *key_length = sizeof(NIST_KEY_CFB_E4);
            break;
        case 5:
            *data_length = sizeof(NIST_TEST_DATA_CFB_E5);
            *iv_length = sizeof(NIST_IV_CFB_E5);
            *key_length = sizeof(NIST_KEY_CFB_E5);
            break;
        case 6:
            *data_length = sizeof(NIST_TEST_DATA_CFB_E6);
            *iv_length = sizeof(NIST_IV_CFB_E6);
            *key_length = sizeof(NIST_KEY_CFB_E6);
            break;
        case 7:
            *data_length = sizeof(NIST_TEST_DATA_CFB_E7);
            *iv_length = sizeof(NIST_IV_CFB_E7);
            *key_length = sizeof(NIST_KEY_CFB_E7);
            break;
        case 8:
            *data_length = sizeof(NIST_TEST_DATA_CFB_E8);
            *iv_length = sizeof(NIST_IV_CFB_E8);
            *key_length = sizeof(NIST_KEY_CFB_E8);
            break;
        case 9:
            *data_length = sizeof(NIST_TEST_DATA_CFB_E9);
            *iv_length = sizeof(NIST_IV_CFB_E9);
            *key_length = sizeof(NIST_KEY_CFB_E9);
            break;
        case 10:
            *data_length = sizeof(NIST_TEST_DATA_CFB_E10);
            *iv_length = sizeof(NIST_IV_CFB_E10);
            *key_length = sizeof(NIST_KEY_CFB_E10);
            break;
        case 11:
            *data_length = sizeof(NIST_TEST_DATA_CFB_E11);
            *iv_length = sizeof(NIST_IV_CFB_E11);
            *key_length = sizeof(NIST_KEY_CFB_E11);
            break;
        case 12:
            *data_length = sizeof(NIST_TEST_DATA_CFB_E12);
            *iv_length = sizeof(NIST_IV_CFB_E12);
            *key_length = sizeof(NIST_KEY_CFB_E12);
            break;
    }

}

void load_test_data(unsigned char *data, unsigned int data_length,
            unsigned char *result,
            unsigned char *iv, unsigned char *expected_iv,
            unsigned int iv_length,
            unsigned char *key, unsigned int key_length,
            unsigned int *lcfb, unsigned int iteration)
{
    switch (iteration) {
        case 1:
            memcpy(data, NIST_TEST_DATA_CFB_E1, data_length);
            memcpy(result, NIST_TEST_RESULT_CFB_E1, data_length);
            memcpy(iv, NIST_IV_CFB_E1, iv_length);
            memcpy(expected_iv, NIST_EXPECTED_IV_CFB_E1, iv_length);
            memcpy(key, NIST_KEY_CFB_E1, key_length);
            *lcfb = NIST_LCFB_E1;
            break;
        case 2:
            memcpy(data, NIST_TEST_DATA_CFB_E2, data_length);
            memcpy(result, NIST_TEST_RESULT_CFB_E2, data_length);
            memcpy(iv, NIST_IV_CFB_E2, iv_length);
            memcpy(expected_iv, NIST_EXPECTED_IV_CFB_E2, iv_length);
            memcpy(key, NIST_KEY_CFB_E2, key_length);
            *lcfb = NIST_LCFB_E2;
            break;
        case 3:
            memcpy(data, NIST_TEST_DATA_CFB_E3, data_length);
            memcpy(result, NIST_TEST_RESULT_CFB_E3, data_length);
            memcpy(iv, NIST_IV_CFB_E3, iv_length);
            memcpy(expected_iv, NIST_EXPECTED_IV_CFB_E3, iv_length);
            memcpy(key, NIST_KEY_CFB_E3, key_length);
            *lcfb = NIST_LCFB_E3;
            break;
        case 4:
            memcpy(data, NIST_TEST_DATA_CFB_E4, data_length);
            memcpy(result, NIST_TEST_RESULT_CFB_E4, data_length);
            memcpy(iv, NIST_IV_CFB_E4, iv_length);
            memcpy(expected_iv, NIST_EXPECTED_IV_CFB_E4, iv_length);
            memcpy(key, NIST_KEY_CFB_E4, key_length);
            *lcfb = NIST_LCFB_E4;
            break;
        case 5:
            memcpy(data, NIST_TEST_DATA_CFB_E5, data_length);
            memcpy(result, NIST_TEST_RESULT_CFB_E5, data_length);
            memcpy(iv, NIST_IV_CFB_E5, iv_length);
            memcpy(expected_iv, NIST_EXPECTED_IV_CFB_E5, iv_length);
            memcpy(key, NIST_KEY_CFB_E5, key_length);
            *lcfb = NIST_LCFB_E5;
            break;
        case 6:
            memcpy(data, NIST_TEST_DATA_CFB_E6, data_length);
            memcpy(result, NIST_TEST_RESULT_CFB_E6, data_length);
            memcpy(iv, NIST_IV_CFB_E6, iv_length);
            memcpy(expected_iv, NIST_EXPECTED_IV_CFB_E6, iv_length);
            memcpy(key, NIST_KEY_CFB_E6, key_length);
            *lcfb = NIST_LCFB_E6;
            break;
        case 7:
            memcpy(data, NIST_TEST_DATA_CFB_E7, data_length);
            memcpy(result, NIST_TEST_RESULT_CFB_E7, data_length);
            memcpy(iv, NIST_IV_CFB_E7, iv_length);
            memcpy(expected_iv, NIST_EXPECTED_IV_CFB_E7, iv_length);
            memcpy(key, NIST_KEY_CFB_E7, key_length);
            *lcfb = NIST_LCFB_E7;
            break;
        case 8:
            memcpy(data, NIST_TEST_DATA_CFB_E8, data_length);
            memcpy(result, NIST_TEST_RESULT_CFB_E8, data_length);
            memcpy(iv, NIST_IV_CFB_E8, iv_length);
            memcpy(expected_iv, NIST_EXPECTED_IV_CFB_E8, iv_length);
            memcpy(key, NIST_KEY_CFB_E8, key_length);
            *lcfb = NIST_LCFB_E8;
            break;
        case 9:
            memcpy(data, NIST_TEST_DATA_CFB_E9, data_length);
            memcpy(result, NIST_TEST_RESULT_CFB_E9, data_length);
            memcpy(iv, NIST_IV_CFB_E9, iv_length);
            memcpy(expected_iv, NIST_EXPECTED_IV_CFB_E9, iv_length);
            memcpy(key, NIST_KEY_CFB_E9, key_length);
            *lcfb = NIST_LCFB_E9;
            break;
        case 10:
            memcpy(data, NIST_TEST_DATA_CFB_E10, data_length);
            memcpy(result, NIST_TEST_RESULT_CFB_E10, data_length);
            memcpy(iv, NIST_IV_CFB_E10, iv_length);
            memcpy(expected_iv, NIST_EXPECTED_IV_CFB_E10, iv_length);
            memcpy(key, NIST_KEY_CFB_E10, key_length);
            *lcfb = NIST_LCFB_E10;
            break;
        case 11:
            memcpy(data, NIST_TEST_DATA_CFB_E11, data_length);
            memcpy(result, NIST_TEST_RESULT_CFB_E11, data_length);
            memcpy(iv, NIST_IV_CFB_E11, iv_length);
            memcpy(expected_iv, NIST_EXPECTED_IV_CFB_E11, iv_length);
            memcpy(key, NIST_KEY_CFB_E11, key_length);
            *lcfb = NIST_LCFB_E11;
            break;
        case 12:
            memcpy(data, NIST_TEST_DATA_CFB_E12, data_length);
            memcpy(result, NIST_TEST_RESULT_CFB_E12, data_length);
            memcpy(iv, NIST_IV_CFB_E12, iv_length);
            memcpy(expected_iv, NIST_EXPECTED_IV_CFB_E12, iv_length);
            memcpy(key, NIST_KEY_CFB_E12, key_length);
            *lcfb = NIST_LCFB_E12;
            break;
    }

}

int kat_aes_cfb(int iteration, int silent)
{
    unsigned int data_length;
    unsigned int iv_length;
    unsigned int key_length;

    get_sizes(&data_length, &iv_length, &key_length, iteration);


    unsigned char iv[iv_length];
    unsigned char tmp_iv[iv_length];
    unsigned char expected_iv[iv_length];
    unsigned char key[key_length];
    unsigned char input_data[data_length];
    unsigned char encrypt[data_length];
    unsigned char decrypt[data_length];
    unsigned char result[data_length];

    int rc = 0;
    unsigned int lcfb;
    memset(encrypt, 0x00, data_length);
    memset(decrypt, 0x00, data_length);

    load_test_data(input_data, data_length, result, iv, expected_iv,
               iv_length, key, key_length, &lcfb, iteration);
    memcpy(tmp_iv, iv, iv_length);

    printf("Test Parameters for iteration = %i\n", iteration);
    printf("key length = %i, data length = %i, iv length = %i,"
           " lcfb = %i\n", key_length, data_length, iv_length, lcfb);

    if (iteration == 3)
    rc = ica_aes_cfb(input_data, encrypt, lcfb, key, key_length, tmp_iv,
             lcfb, 1);
    else
    rc = ica_aes_cfb(input_data, encrypt, data_length, key, key_length,
             tmp_iv, lcfb, 1);
    if (rc) {
        printf("ica_aes_cfb encrypt failed with rc = %i\n", rc);
        dump_cfb_data(iv, iv_length, key, key_length, input_data,
                  data_length, encrypt);
    }
    if (!silent && !rc) {
        printf("Encrypt:\n");
        dump_cfb_data(iv, iv_length, key, key_length, input_data,
                  data_length, encrypt);
    }

    if (memcmp(result, encrypt, data_length)) {
        printf("Encryption Result does not match the known ciphertext!\n");
        printf("Expected data:\n");
        dump_array(result, data_length);
        printf("Encryption Result:\n");
        dump_array(encrypt, data_length);
        rc++;
    }

    if (memcmp(expected_iv, tmp_iv, iv_length)) {
        printf("Update of IV does not match the expected IV!\n");
        printf("Expected IV:\n");
        dump_array(expected_iv, iv_length);
        printf("Updated IV:\n");
        dump_array(tmp_iv, iv_length);
        printf("Original IV:\n");
        dump_array(iv, iv_length);
        rc++;
    }
    if (rc) {
        printf("AES OFB test exited after encryption\n");
        return rc;
    }

    memcpy(tmp_iv, iv, iv_length);
    if (iteration == 3)
    rc = ica_aes_cfb(encrypt, decrypt, lcfb, key, key_length, tmp_iv,
             lcfb, 0);
    else
    rc = ica_aes_cfb(encrypt, decrypt, data_length, key, key_length,
             tmp_iv, lcfb, 0);
    if (rc) {
        printf("ica_aes_cfb decrypt failed with rc = %i\n", rc);
        dump_cfb_data(iv, iv_length, key, key_length, encrypt,
                  data_length, decrypt);
        return rc;
    }
    if (!silent && !rc) {
        printf("Decrypt:\n");
        dump_cfb_data(iv, iv_length, key, key_length, encrypt,
                  data_length, decrypt);
    }

    if (memcmp(decrypt, input_data, data_length)) {
        printf("Decryption Result does not match the original data!\n");
        printf("Original data:\n");
        dump_array(input_data, data_length);
        printf("Decryption Result:\n");
        dump_array(decrypt, data_length);
        rc++;
    }
    return rc;
}

int load_random_test_data(unsigned char *data, unsigned int data_length,
                   unsigned char *iv, unsigned int iv_length,
                   unsigned char *key, unsigned int key_length)
{
    int rc;
    rc = ica_random_number_generate(data_length, data);
    if (rc) {
        printf("ica_random_number_generate with rc = %i errnor = %i\n",
               rc, errno);
        return rc;
    }
    rc = ica_random_number_generate(iv_length, iv);
    if (rc) {
        printf("ica_random_number_generate with rc = %i errnor = %i\n",
               rc, errno);
        return rc;
    }
    rc = ica_random_number_generate(key_length, key);
    if (rc) {
        printf("ica_random_number_generate with rc = %i errnor = %i\n",
               rc, errno);
        return rc;
    }
    return rc;
}

int random_aes_cfb(int iteration, int silent, unsigned int data_length,
           unsigned int lcfb)
{
    unsigned int iv_length = sizeof(ica_aes_vector_t);
    unsigned int key_length = AES_KEY_LEN128;

    unsigned char iv[iv_length];
    unsigned char tmp_iv[iv_length];
    unsigned char key[key_length];
    unsigned char input_data[data_length];
    unsigned char encrypt[data_length];
    unsigned char decrypt[data_length];

    int rc = 0;
    for (key_length = AES_KEY_LEN128; key_length <= AES_KEY_LEN256; key_length += 8) {
    memset(encrypt, 0x00, data_length);
    memset(decrypt, 0x00, data_length);

    load_random_test_data(input_data, data_length, iv, iv_length, key,
                  key_length);
    memcpy(tmp_iv, iv, iv_length);

    printf("Test Parameters for iteration = %i\n", iteration);
    printf("key length = %i, data length = %i, iv length = %i,"
           " lcfb = %i\n", key_length, data_length, iv_length, lcfb);

    rc = ica_aes_cfb(input_data, encrypt, data_length, key, key_length,
             tmp_iv, lcfb, 1);
    if (rc) {
        printf("ica_aes_cfb encrypt failed with rc = %i\n", rc);
        dump_cfb_data(iv, iv_length, key, key_length, input_data,
                  data_length, encrypt);
    }
    if (!silent && !rc) {
        printf("Encrypt:\n");
        dump_cfb_data(iv, iv_length, key, key_length, input_data,
                  data_length, encrypt);
    }

    if (rc) {
        printf("AES OFB test exited after encryption\n");
        return rc;
    }

    memcpy(tmp_iv, iv, iv_length);

    rc = ica_aes_cfb(encrypt, decrypt, data_length, key, key_length,
             tmp_iv, lcfb, 0);
    if (rc) {
        printf("ica_aes_cfb decrypt failed with rc = %i\n", rc);
        dump_cfb_data(iv, iv_length, key, key_length, encrypt,
                  data_length, decrypt);
        return rc;
    }


    if (!silent && !rc) {
        printf("Decrypt:\n");
        dump_cfb_data(iv, iv_length, key, key_length, encrypt,
                  data_length, decrypt);
    }

    if (memcmp(decrypt, input_data, data_length)) {
        printf("Decryption Result does not match the original data!\n");
        printf("Original data:\n");
        dump_array(input_data, data_length);
        printf("Decryption Result:\n");
        dump_array(decrypt, data_length);
        rc++;
    }
    }
    return rc;
}

int main(int argc, char **argv)
{
    unsigned int silent = 0;
    unsigned int endless = 0;
    if (argc > 1) {
        if (strstr(argv[1], "silent"))
            silent = 1;
        if (strstr(argv[1], "endless"))
            endless = 1;
    }
    int rc = 0;
    int error_count = 0;
    int iteration;
    for(iteration = 1; iteration <= NR_TESTS; iteration++)    {
        rc = kat_aes_cfb(iteration, silent);
        if (rc) {
            printf("kat_aes_cfb failed with rc = %i\n", rc);
            error_count++;
        } else
            printf("kat_aes_cfb finished successfuly\n");

    }

    unsigned int data_length = 1;
    unsigned int lcfb = 1;
    unsigned int j;
    for(iteration = 1; iteration <= NR_RANDOM_TESTS; iteration++)    {
        for (j = 1; j <= 3; j++) {
            int silent = 1;
            if (!(data_length % lcfb)) {
            rc = random_aes_cfb(iteration, silent, data_length, lcfb);
            if (rc) {
                printf("random_aes_cfb failed with rc = %i\n", rc);
                error_count++;
            } else
                printf("random_aes_cfb finished successfuly\n");
            }
            switch (j) {
                case 1:
                    lcfb = 1;
                    break;
                case 2:
                    lcfb = 8;
                    break;
                case 3:
                    lcfb = 16;
                    break;
            }
        }
        if (data_length == 1)
            data_length = 8;
        else
            data_length += 8;
    }
    if (error_count)
        printf("%i testcases failed\n", error_count);
    else
        printf("All testcases finished successfully\n");

    return rc;
}
```

## AES with CTR mode example

```
/* This program is released under the Common Public License V1.0
 *
 * You should have received a copy of Common Public License V1.0 along with
 * with this program.
 */

/* Copyright IBM Corp. 2010, 2011 */
#include <fcntl.h>
#include <sys/errno.h>
#include <stdio.h>
#include <string.h>
#include <strings.h>
#include <stdlib.h>
#include "ica_api.h"

#define NR_TESTS 7

/* CTR data - 1 for AES128 */
unsigned char NIST_KEY_CTR_E1[] = {
    0x2b, 0x7e, 0x15, 0x16, 0x28, 0xae, 0xd2, 0xa6,
    0xab, 0xf7, 0x15, 0x88, 0x09, 0xcf, 0x4f, 0x3c,
};

unsigned char NIST_IV_CTR_E1[] = {
    0xf0, 0xf1, 0xf2, 0xf3, 0xf4, 0xf5, 0xf6, 0xf7,
    0xf8, 0xf9, 0xfa, 0xfb, 0xfc, 0xfd, 0xfe, 0xff,
};

unsigned char NIST_EXPECTED_IV_CTR_E1[] = {
    0xf0, 0xf1, 0xf2, 0xf3, 0xf4, 0xf5, 0xf6, 0xf7,
    0xf8, 0xf9, 0xfa, 0xfb, 0xfc, 0xfd, 0xff, 0x00,
};

unsigned char NIST_TEST_DATA_CTR_E1[] = {
    0x6b, 0xc1, 0xbe, 0xe2, 0x2e, 0x40, 0x9f, 0x96,
    0xe9, 0x3d, 0x7e, 0x11, 0x73, 0x93, 0x17, 0x2a,
};

unsigned char NIST_TEST_RESULT_CTR_E1[] = {
    0x87, 0x4d, 0x61, 0x91, 0xb6, 0x20, 0xe3, 0x26,
    0x1b, 0xef, 0x68, 0x64, 0x99, 0x0d, 0xb6, 0xce,
};

/* CTR data - 2 for AES128 */
unsigned char NIST_KEY_CTR_E2[] = {
    0x2b, 0x7e, 0x15, 0x16, 0x28, 0xae, 0xd2, 0xa6,
    0xab, 0xf7, 0x15, 0x88, 0x09, 0xcf, 0x4f, 0x3c,
};

unsigned char NIST_IV_CTR_E2[] = {
    0xf0, 0xf1, 0xf2, 0xf3, 0xf4, 0xf5, 0xf6, 0xf7,
    0xf8, 0xf9, 0xfa, 0xfb, 0xfc, 0xfd, 0xfe, 0xff,
};

unsigned char NIST_EXPECTED_IV_CTR_E2[] = {
    0xf0, 0xf1, 0xf2, 0xf3, 0xf4, 0xf5, 0xf6, 0xf7,
    0xf8, 0xf9, 0xfa, 0xfb, 0xfc, 0xfd, 0xff, 0x03,
};

unsigned char NIST_TEST_DATA_CTR_E2[] = {
    0x6b, 0xc1, 0xbe, 0xe2, 0x2e, 0x40, 0x9f, 0x96,
    0xe9, 0x3d, 0x7e, 0x11, 0x73, 0x93, 0x17, 0x2a,
    0xae, 0x2d, 0x8a, 0x57, 0x1e, 0x03, 0xac, 0x9c,
    0x9e, 0xb7, 0x6f, 0xac, 0x45, 0xaf, 0x8e, 0x51,
    0x30, 0xc8, 0x1c, 0x46, 0xa3, 0x5c, 0xe4, 0x11,
    0xe5, 0xfb, 0xc1, 0x19, 0x1a, 0x0a, 0x52, 0xef,
    0xf6, 0x9f, 0x24, 0x45, 0xdf, 0x4f, 0x9b, 0x17,
    0xad, 0x2b, 0x41, 0x7b, 0xe6, 0x6c, 0x37, 0x10,
};

unsigned char NIST_TEST_RESULT_CTR_E2[] = {
    0x87, 0x4d, 0x61, 0x91, 0xb6, 0x20, 0xe3, 0x26,
    0x1b, 0xef, 0x68, 0x64, 0x99, 0x0d, 0xb6, 0xce,
    0x98, 0x06, 0xf6, 0x6b, 0x79, 0x70, 0xfd, 0xff,
    0x86, 0x17, 0x18, 0x7b, 0xb9, 0xff, 0xfd, 0xff,
    0x5a, 0xe4, 0xdf, 0x3e, 0xdb, 0xd5, 0xd3, 0x5e,
    0x5b, 0x4f, 0x09, 0x02, 0x0d, 0xb0, 0x3e, 0xab,
    0x1e, 0x03, 0x1d, 0xda, 0x2f, 0xbe, 0x03, 0xd1,
    0x79, 0x21, 0x70, 0xa0, 0xf3, 0x00, 0x9c, 0xee,
};

/* CTR data - 3 - for AES192 */
unsigned char NIST_KEY_CTR_E3[] = {
    0x60, 0x3d, 0xeb, 0x10, 0x15, 0xca, 0x71, 0xbe,
    0x2b, 0x73, 0xae, 0xf0, 0x85, 0x7d, 0x77, 0x81,
    0x1f, 0x35, 0x2c, 0x07, 0x3b, 0x61, 0x08, 0xd7,
    0x2d, 0x98, 0x10, 0xa3, 0x09, 0x14, 0xdf, 0xf4,
};

unsigned char NIST_IV_CTR_E3[] = {
    0xf0, 0xf1, 0xf2, 0xf3, 0xf4, 0xf5, 0xf6, 0xf7,
    0xf8, 0xf9, 0xfa, 0xfb, 0xfc, 0xfd, 0xfe, 0xff,
};

unsigned char NIST_EXPECTED_IV_CTR_E3[] = {
    0xf0, 0xf1, 0xf2, 0xf3, 0xf4, 0xf5, 0xf6, 0xf7,
    0xf8, 0xf9, 0xfa, 0xfb, 0xfc, 0xfd, 0xff, 0x00,
};

unsigned char NIST_TEST_DATA_CTR_E3[] = {
    0x6b, 0xc1, 0xbe, 0xe2, 0x2e, 0x40, 0x9f, 0x96,
    0xe9, 0x3d, 0x7e, 0x11, 0x73, 0x93, 0x17, 0x2a,
};

unsigned char NIST_TEST_RESULT_CTR_E3[] = {
    0x60, 0x1e, 0xc3, 0x13, 0x77, 0x57, 0x89, 0xa5,
    0xb7, 0xa7, 0xf5, 0x04, 0xbb, 0xf3, 0xd2, 0x28,
};

/* CTR data - 4 - for AES192 */
unsigned char NIST_KEY_CTR_E4[] = {
    0x60, 0x3d, 0xeb, 0x10, 0x15, 0xca, 0x71, 0xbe,
    0x2b, 0x73, 0xae, 0xf0, 0x85, 0x7d, 0x77, 0x81,
    0x1f, 0x35, 0x2c, 0x07, 0x3b, 0x61, 0x08, 0xd7,
    0x2d, 0x98, 0x10, 0xa3, 0x09, 0x14, 0xdf, 0xf4,
};

unsigned char NIST_IV_CTR_E4[] = {
    0xf0, 0xf1, 0xf2, 0xf3, 0xf4, 0xf5, 0xf6, 0xf7,
    0xf8, 0xf9, 0xfa, 0xfb, 0xfc, 0xfd, 0xff, 0x00,
};

unsigned char NIST_EXPECTED_IV_CTR_E4[] = {
    0xf0, 0xf1, 0xf2, 0xf3, 0xf4, 0xf5, 0xf6, 0xf7,
    0xf8, 0xf9, 0xfa, 0xfb, 0xfc, 0xfd, 0xff, 0x01,
};

unsigned char NIST_TEST_DATA_CTR_E4[] = {
    0xae, 0x2d, 0x8a, 0x57, 0x1e, 0x03, 0xac, 0x9c,
    0x9e, 0xb7, 0x6f, 0xac, 0x45, 0xaf, 0x8e, 0x51,
};

unsigned char NIST_TEST_RESULT_CTR_E4[] = {
    0xf4, 0x43, 0xe3, 0xca, 0x4d, 0x62, 0xb5, 0x9a,
    0xca, 0x84, 0xe9, 0x90, 0xca, 0xca, 0xf5, 0xc5,
};

/* CTR data 5 - for AES 256 */
unsigned char NIST_KEY_CTR_E5[] = {
    0x60, 0x3d, 0xeb, 0x10, 0x15, 0xca, 0x71, 0xbe,
    0x2b, 0x73, 0xae, 0xf0, 0x85, 0x7d, 0x77, 0x81,
    0x1f, 0x35, 0x2c, 0x07, 0x3b, 0x61, 0x08, 0xd7,
    0x2d, 0x98, 0x10, 0xa3, 0x09, 0x14, 0xdf, 0xf4,
};

unsigned char NIST_IV_CTR_E5[] = {
    0xf0, 0xf1, 0xf2, 0xf3, 0xf4, 0xf5, 0xf6, 0xf7,
    0xf8, 0xf9, 0xfa, 0xfb, 0xfc, 0xfd, 0xfe, 0xff,
};

unsigned char NIST_EXPECTED_IV_CTR_E5[] = {
    0xf0, 0xf1, 0xf2, 0xf3, 0xf4, 0xf5, 0xf6, 0xf7,
    0xf8, 0xf9, 0xfa, 0xfb, 0xfc, 0xfd, 0xff, 0x03,
};

unsigned char NIST_TEST_DATA_CTR_E5[] = {
    0x6b, 0xc1, 0xbe, 0xe2, 0x2e, 0x40, 0x9f, 0x96,
    0xe9, 0x3d, 0x7e, 0x11, 0x73, 0x93, 0x17, 0x2a,
    0xae, 0x2d, 0x8a, 0x57, 0x1e, 0x03, 0xac, 0x9c,
    0x9e, 0xb7, 0x6f, 0xac, 0x45, 0xaf, 0x8e, 0x51,
    0x30, 0xc8, 0x1c, 0x46, 0xa3, 0x5c, 0xe4, 0x11,
    0xe5, 0xfb, 0xc1, 0x19, 0x1a, 0x0a, 0x52, 0xef,
    0xf6, 0x9f, 0x24, 0x45, 0xdf, 0x4f, 0x9b, 0x17,
    0xad, 0x2b, 0x41, 0x7b, 0xe6, 0x6c, 0x37, 0x10,
};

unsigned char NIST_TEST_RESULT_CTR_E5[] = {
    0x60, 0x1e, 0xc3, 0x13, 0x77, 0x57, 0x89, 0xa5,
    0xb7, 0xa7, 0xf5, 0x04, 0xbb, 0xf3, 0xd2, 0x28,
    0xf4, 0x43, 0xe3, 0xca, 0x4d, 0x62, 0xb5, 0x9a,
    0xca, 0x84, 0xe9, 0x90, 0xca, 0xca, 0xf5, 0xc5,
    0x2b, 0x09, 0x30, 0xda, 0xa2, 0x3d, 0xe9, 0x4c,
    0xe8, 0x70, 0x17, 0xba, 0x2d, 0x84, 0x98, 0x8d,
    0xdf, 0xc9, 0xc5, 0x8d, 0xb6, 0x7a, 0xad, 0xa6,
    0x13, 0xc2, 0xdd, 0x08, 0x45, 0x79, 0x41, 0xa6,
};

/* CTR data 6 - for AES 256.
 * Data is != BLOCK_SIZE */
unsigned char NIST_KEY_CTR_E6[] = {
    0x60, 0x3d, 0xeb, 0x10, 0x15, 0xca, 0x71, 0xbe,
    0x2b, 0x73, 0xae, 0xf0, 0x85, 0x7d, 0x77, 0x81,
    0x1f, 0x35, 0x2c, 0x07, 0x3b, 0x61, 0x08, 0xd7,
    0x2d, 0x98, 0x10, 0xa3, 0x09, 0x14, 0xdf, 0xf4,
};

unsigned char NIST_IV_CTR_E6[] = {
    0xf0, 0xf1, 0xf2, 0xf3, 0xf4, 0xf5, 0xf6, 0xf7,
    0xf8, 0xf9, 0xfa, 0xfb, 0xfc, 0xfd, 0xfe, 0xff,
};

unsigned char NIST_EXPECTED_IV_CTR_E6[] = {
    0xf0, 0xf1, 0xf2, 0xf3, 0xf4, 0xf5, 0xf6, 0xf7,
    0xf8, 0xf9, 0xfa, 0xfb, 0xfc, 0xfd, 0xff, 0x03,
};

unsigned char NIST_TEST_DATA_CTR_E6[] = {
    0x6b, 0xc1, 0xbe, 0xe2, 0x2e, 0x40, 0x9f, 0x96,
    0xe9, 0x3d, 0x7e, 0x11, 0x73, 0x93, 0x17, 0x2a,
    0xae, 0x2d, 0x8a, 0x57, 0x1e, 0x03, 0xac, 0x9c,
    0x9e, 0xb7, 0x6f, 0xac, 0x45, 0xaf, 0x8e, 0x51,
    0x30, 0xc8, 0x1c, 0x46, 0xa3, 0x5c, 0xe4, 0x11,
    0xe5, 0xfb, 0xc1, 0x19, 0x1a, 0x0a, 0x52, 0xef,
    0xf6, 0x9f, 0x24, 0x45, 0xdf, 0x4f, 0x9b, 0x17,
};

unsigned char NIST_TEST_RESULT_CTR_E6[] = {
    0x60, 0x1e, 0xc3, 0x13, 0x77, 0x57, 0x89, 0xa5,
    0xb7, 0xa7, 0xf5, 0x04, 0xbb, 0xf3, 0xd2, 0x28,
    0xf4, 0x43, 0xe3, 0xca, 0x4d, 0x62, 0xb5, 0x9a,
    0xca, 0x84, 0xe9, 0x90, 0xca, 0xca, 0xf5, 0xc5,
    0x2b, 0x09, 0x30, 0xda, 0xa2, 0x3d, 0xe9, 0x4c,
    0xe8, 0x70, 0x17, 0xba, 0x2d, 0x84, 0x98, 0x8d,
    0xdf, 0xc9, 0xc5, 0x8d, 0xb6, 0x7a, 0xad, 0xa6,
};

/* CTR data 7 - for AES 256
 * Counter as big as the data. Therefore the counter
 * should not be updated. Because it is already pre
 * computed. */
unsigned char NIST_KEY_CTR_E7[] = {
    0x60, 0x3d, 0xeb, 0x10, 0x15, 0xca, 0x71, 0xbe,
    0x2b, 0x73, 0xae, 0xf0, 0x85, 0x7d, 0x77, 0x81,
    0x1f, 0x35, 0x2c, 0x07, 0x3b, 0x61, 0x08, 0xd7,
    0x2d, 0x98, 0x10, 0xa3, 0x09, 0x14, 0xdf, 0xf4,
};

unsigned char NIST_IV_CTR_E7[] = {
    0xf0, 0xf1, 0xf2, 0xf3, 0xf4, 0xf5, 0xf6, 0xf7,
    0xf8, 0xf9, 0xfa, 0xfb, 0xfc, 0xfd, 0xfe, 0xff,
    0xf0, 0xf1, 0xf2, 0xf3, 0xf4, 0xf5, 0xf6, 0xf7,
    0xf8, 0xf9, 0xfa, 0xfb, 0xfc, 0xfd, 0xff, 0x00,
    0xf0, 0xf1, 0xf2, 0xf3, 0xf4, 0xf5, 0xf6, 0xf7,
    0xf8, 0xf9, 0xfa, 0xfb, 0xfc, 0xfd, 0xff, 0x01,
    0xf0, 0xf1, 0xf2, 0xf3, 0xf4, 0xf5, 0xf6, 0xf7,
    0xf8, 0xf9, 0xfa, 0xfb, 0xfc, 0xfd, 0xff, 0x02,
};

unsigned char NIST_EXPECTED_IV_CTR_E7[] = {
    0xf0, 0xf1, 0xf2, 0xf3, 0xf4, 0xf5, 0xf6, 0xf7,
    0xf8, 0xf9, 0xfa, 0xfb, 0xfc, 0xfd, 0xfe, 0xff,
    0xf0, 0xf1, 0xf2, 0xf3, 0xf4, 0xf5, 0xf6, 0xf7,
    0xf8, 0xf9, 0xfa, 0xfb, 0xfc, 0xfd, 0xff, 0x00,
    0xf0, 0xf1, 0xf2, 0xf3, 0xf4, 0xf5, 0xf6, 0xf7,
    0xf8, 0xf9, 0xfa, 0xfb, 0xfc, 0xfd, 0xff, 0x01,
    0xf0, 0xf1, 0xf2, 0xf3, 0xf4, 0xf5, 0xf6, 0xf7,
    0xf8, 0xf9, 0xfa, 0xfb, 0xfc, 0xfd, 0xff, 0x02,
};

unsigned char NIST_TEST_DATA_CTR_E7[] = {
    0x6b, 0xc1, 0xbe, 0xe2, 0x2e, 0x40, 0x9f, 0x96,
    0xe9, 0x3d, 0x7e, 0x11, 0x73, 0x93, 0x17, 0x2a,
    0xae, 0x2d, 0x8a, 0x57, 0x1e, 0x03, 0xac, 0x9c,
    0x9e, 0xb7, 0x6f, 0xac, 0x45, 0xaf, 0x8e, 0x51,
    0x30, 0xc8, 0x1c, 0x46, 0xa3, 0x5c, 0xe4, 0x11,
    0xe5, 0xfb, 0xc1, 0x19, 0x1a, 0x0a, 0x52, 0xef,
    0xf6, 0x9f, 0x24, 0x45, 0xdf, 0x4f, 0x9b, 0x17,
    0xad, 0x2b, 0x41, 0x7b, 0xe6, 0x6c, 0x37, 0x10,
};

unsigned char NIST_TEST_RESULT_CTR_E7[] = {
    0x60, 0x1e, 0xc3, 0x13, 0x77, 0x57, 0x89, 0xa5,
    0xb7, 0xa7, 0xf5, 0x04, 0xbb, 0xf3, 0xd2, 0x28,
    0xf4, 0x43, 0xe3, 0xca, 0x4d, 0x62, 0xb5, 0x9a,
    0xca, 0x84, 0xe9, 0x90, 0xca, 0xca, 0xf5, 0xc5,
    0x2b, 0x09, 0x30, 0xda, 0xa2, 0x3d, 0xe9, 0x4c,
    0xe8, 0x70, 0x17, 0xba, 0x2d, 0x84, 0x98, 0x8d,
    0xdf, 0xc9, 0xc5, 0x8d, 0xb6, 0x7a, 0xad, 0xa6,
    0x13, 0xc2, 0xdd, 0x08, 0x45, 0x79, 0x41, 0xa6,
};


void dump_array(unsigned char *ptr, unsigned int size)
{
    unsigned char *ptr_end;
    unsigned char *h;
    int i = 1;

    h = ptr;
    ptr_end = ptr + size;
    while (h < (unsigned char *)ptr_end) {
        printf("0x%02x ",(unsigned char ) *h);
        h++;
        if (i == 8) {
            printf("\n");
            i = 1;
        } else {
            ++i;
        }
    }
    printf("\n");
}

void dump_ctr_data(unsigned char *iv, unsigned int iv_length,
                   unsigned char *key, unsigned int key_length,
                   unsigned char *input_data, unsigned int data_length,
                   unsigned char *output_data)
{
    printf("IV \n");
    dump_array(iv, iv_length);
    printf("Key \n");
    dump_array(key, key_length);
    printf("Input Data\n");
    dump_array(input_data, data_length);
    printf("Output Data\n");
    dump_array(output_data, data_length);
```

```
}

void get_sizes(unsigned int *data_length, unsigned int *iv_length,
           unsigned int *key_length, unsigned int iteration)
{
    switch (iteration) {
        case 1:
            *data_length = sizeof(NIST_TEST_DATA_CTR_E1);
            *iv_length = sizeof(NIST_IV_CTR_E1);
            *key_length = sizeof(NIST_KEY_CTR_E1);
            break;
        case 2:
            *data_length = sizeof(NIST_TEST_DATA_CTR_E2);
            *iv_length = sizeof(NIST_IV_CTR_E2);
            *key_length = sizeof(NIST_KEY_CTR_E2);
            break;
        case 3:
            *data_length = sizeof(NIST_TEST_DATA_CTR_E3);
            *iv_length = sizeof(NIST_IV_CTR_E3);
            *key_length = sizeof(NIST_KEY_CTR_E3);
            break;
        case 4:
            *data_length = sizeof(NIST_TEST_DATA_CTR_E4);
            *iv_length = sizeof(NIST_IV_CTR_E4);
            *key_length = sizeof(NIST_KEY_CTR_E4);
            break;
        case 5:
            *data_length = sizeof(NIST_TEST_DATA_CTR_E5);
            *iv_length = sizeof(NIST_IV_CTR_E5);
            *key_length = sizeof(NIST_KEY_CTR_E5);
            break;
        case 6:
            *data_length = sizeof(NIST_TEST_DATA_CTR_E6);
            *iv_length = sizeof(NIST_IV_CTR_E6);
            *key_length = sizeof(NIST_KEY_CTR_E6);
            break;
        case 7:
            *data_length = sizeof(NIST_TEST_DATA_CTR_E7);
            *iv_length = sizeof(NIST_IV_CTR_E7);
            *key_length = sizeof(NIST_KEY_CTR_E7);
            break;
    }

}

void load_test_data(unsigned char *data, unsigned int data_length,
            unsigned char *result,
            unsigned char *iv, unsigned char *expected_iv,
            unsigned int iv_length,
            unsigned char *key, unsigned int key_length,
            unsigned int iteration)
{
    switch (iteration) {
        case 1:
            memcpy(data, NIST_TEST_DATA_CTR_E1, data_length);
            memcpy(result, NIST_TEST_RESULT_CTR_E1, data_length);
            memcpy(iv, NIST_IV_CTR_E1, iv_length);
            memcpy(expected_iv, NIST_EXPECTED_IV_CTR_E1, iv_length);
            memcpy(key, NIST_KEY_CTR_E1, key_length);
            break;
        case 2:
            memcpy(data, NIST_TEST_DATA_CTR_E2, data_length);
            memcpy(result, NIST_TEST_RESULT_CTR_E2, data_length);
            memcpy(iv, NIST_IV_CTR_E2, iv_length);
            memcpy(expected_iv, NIST_EXPECTED_IV_CTR_E2, iv_length);
            memcpy(key, NIST_KEY_CTR_E2, key_length);
            break;
        case 3:
            memcpy(data, NIST_TEST_DATA_CTR_E3, data_length);
            memcpy(result, NIST_TEST_RESULT_CTR_E3, data_length);
            memcpy(iv, NIST_IV_CTR_E3, iv_length);
            memcpy(expected_iv, NIST_EXPECTED_IV_CTR_E3, iv_length);
            memcpy(key, NIST_KEY_CTR_E3, key_length);
            break;
        case 4:
            memcpy(data, NIST_TEST_DATA_CTR_E4, data_length);
            memcpy(result, NIST_TEST_RESULT_CTR_E4, data_length);
            memcpy(iv, NIST_IV_CTR_E4, iv_length);
            memcpy(expected_iv, NIST_EXPECTED_IV_CTR_E4, iv_length);
            memcpy(key, NIST_KEY_CTR_E4, key_length);
            break;
        case 5:
            memcpy(data, NIST_TEST_DATA_CTR_E5, data_length);
            memcpy(result, NIST_TEST_RESULT_CTR_E5, data_length);
            memcpy(iv, NIST_IV_CTR_E5, iv_length);
            memcpy(expected_iv, NIST_EXPECTED_IV_CTR_E5, iv_length);
            memcpy(key, NIST_KEY_CTR_E5, key_length);
            break;
        case 6:
            memcpy(data, NIST_TEST_DATA_CTR_E6, data_length);
            memcpy(result, NIST_TEST_RESULT_CTR_E6, data_length);
            memcpy(iv, NIST_IV_CTR_E6, iv_length);
            memcpy(expected_iv, NIST_EXPECTED_IV_CTR_E6, iv_length);
            memcpy(key, NIST_KEY_CTR_E6, key_length);
            break;
        case 7:
            memcpy(data, NIST_TEST_DATA_CTR_E7, data_length);
            memcpy(result, NIST_TEST_RESULT_CTR_E7, data_length);
            memcpy(iv, NIST_IV_CTR_E7, iv_length);
            memcpy(expected_iv, NIST_EXPECTED_IV_CTR_E7, iv_length);
            memcpy(key, NIST_KEY_CTR_E7, key_length);
            break;
    }

}

int random_aes_ctr(int iteration, int silent, unsigned int data_length, unsigned int iv_length)
{
    unsigned int key_length = AES_KEY_LEN256;
    if (data_length % sizeof(ica_aes_vector_t))
        iv_length = sizeof(ica_aes_vector_t);

    printf("Test Parameters for iteration = %i\n", iteration);
    printf("key length = %i, data length = %i, iv length = %i\n",
           key_length, data_length, iv_length);

    unsigned char iv[iv_length];
    unsigned char tmp_iv[iv_length];
    unsigned char key[key_length];
    unsigned char input_data[data_length];
    unsigned char encrypt[data_length];
    unsigned char decrypt[data_length];

    int rc = 0;
    rc = ica_random_number_generate(data_length, input_data);
    if (rc) {
        printf("random number generate returned rc = %i, errno = %i\n", rc, errno);
        return rc;
    }
    rc = ica_random_number_generate(iv_length, iv);
    if (rc) {
        printf("random number generate returned rc = %i, errno = %i\n", rc, errno);
        return rc;
    }

    rc = ica_random_number_generate(key_length, key);
    if (rc) {
        printf("random number generate returned rc = %i, errno = %i\n", rc, errno);
        return rc;
    }
    memcpy(tmp_iv, iv, iv_length);

    rc = ica_aes_ctr(input_data, encrypt, data_length, key, key_length,
             tmp_iv, 32, 1);
    if (rc) {
        printf("ica_aes_ctr encrypt failed with rc = %i\n", rc);
        dump_ctr_data(iv, iv_length, key, key_length, input_data,
                  data_length, encrypt);
        return rc;
    }
    if (!silent && !rc) {
        printf("Encrypt:\n");
        dump_ctr_data(iv, iv_length, key, key_length, input_data,
                  data_length, encrypt);
    }

    memcpy(tmp_iv, iv, iv_length);
    rc = ica_aes_ctr(encrypt, decrypt, data_length, key, key_length,
             tmp_iv, 32, 0);
    if (rc) {
        printf("ica_aes_ctr decrypt failed with rc = %i\n", rc);
        dump_ctr_data(iv, iv_length, key, key_length, encrypt,
                  data_length, decrypt);
        return rc;
    }


    if (!silent && !rc) {
        printf("Decrypt:\n");
        dump_ctr_data(iv, iv_length, key, key_length, encrypt,
                  data_length, decrypt);
    }

    if (memcmp(decrypt, input_data, data_length)) {
        printf("Decryption Result does not match the original data!\n");
        printf("Original data:\n");
        dump_array(input_data, data_length);
        printf("Decryption Result:\n");
        dump_array(decrypt, data_length);
        rc++;
    }
    return rc;
}

int kat_aes_ctr(int iteration, int silent)
{
    unsigned int data_length;
    unsigned int iv_length;
    unsigned int key_length;

    get_sizes(&data_length, &iv_length, &key_length, iteration);

    printf("Test Parameters for iteration = %i\n", iteration);
    printf("key length = %i, data length = %i, iv length = %i\n",
           key_length, data_length, iv_length);

    unsigned char iv[iv_length];
    unsigned char tmp_iv[iv_length];
    unsigned char expected_iv[iv_length];
    unsigned char key[key_length];
    unsigned char input_data[data_length];
    unsigned char encrypt[data_length];
    unsigned char decrypt[data_length];
    unsigned char result[data_length];

    int rc = 0;

    load_test_data(input_data, data_length, result, iv, expected_iv,
               iv_length, key, key_length, iteration);
    memcpy(tmp_iv, iv, iv_length);

    if (iv_length == 16)
        rc = ica_aes_ctr(input_data, encrypt, data_length, key, key_length,
                 tmp_iv, 32, 1);
    else
        rc = ica_aes_ctrlist(input_data, encrypt, data_length, key, key_length,
                 tmp_iv, 1);
    if (rc) {
        printf("ica_aes_ctr encrypt failed with rc = %i\n", rc);
        dump_ctr_data(iv, iv_length, key, key_length, input_data,
                  data_length, encrypt);
    }
    if (!silent && !rc) {
        printf("Encrypt:\n");
        dump_ctr_data(iv, iv_length, key, key_length, input_data,
                  data_length, encrypt);
    }

    if (memcmp(result, encrypt, data_length)) {
        printf("Encryption Result does not match the known ciphertext!\n");
        printf("Expected data:\n");
        dump_array(result, data_length);
        printf("Encryption Result:\n");
        dump_array(encrypt, data_length);
        rc++;
    }

    if (memcmp(expected_iv, tmp_iv, iv_length)) {
        printf("Update of IV does not match the expected IV!\n");
        printf("Expected IV:\n");
        dump_array(expected_iv, iv_length);
        printf("Updated IV:\n");
        dump_array(tmp_iv, iv_length);
        printf("Original IV:\n");
        dump_array(iv, iv_length);
        rc++;
    }
    if (rc) {
        printf("AES CTR test exited after encryption\n");
        return rc;
    }

    memcpy(tmp_iv, iv, iv_length);
    rc = ica_aes_ctr(encrypt, decrypt, data_length, key, key_length,
             tmp_iv, 32,0);
    if (rc) {
        printf("ica_aes_ctr decrypt failed with rc = %i\n", rc);
        dump_ctr_data(iv, iv_length, key, key_length, encrypt,
                  data_length, decrypt);
        return rc;
    }


    if (!silent && !rc) {
        printf("Decrypt:\n");
        dump_ctr_data(iv, iv_length, key, key_length, encrypt,
                  data_length, decrypt);
    }

    if (memcmp(decrypt, input_data, data_length)) {
        printf("Decryption Result does not match the original data!\n");
        printf("Original data:\n");
        dump_array(input_data, data_length);
        printf("Decryption Result:\n");
        dump_array(decrypt, data_length);
        rc++;
    }
    return rc;
}

int main(int argc, char **argv)
{
    // Default mode is 0. ECB,CBC and CFQ tests will be performed.
    unsigned int silent = 0;
    unsigned int endless = 0;
    if (argc > 1) {
        if (strstr(argv[1], "silent"))
            silent = 1;
        if (strstr(argv[1], "endless"))
            endless = 1;
    }
    int rc = 0;
    int error_count = 0;
    int iteration;
    if (!endless)
    for(iteration = 1; iteration <= NR_TESTS; iteration++)    {
        rc = kat_aes_ctr(iteration, silent);
        if (rc) {
            printf("kat_aes_ctr failed with rc = %i\n", rc);
            error_count++;
        } else
            printf("kat_aes_ctr finished successfuly\n");

    }
    int i = 0;
    if (endless)
    while (1) {
        printf("i = %i\n",i);
        silent = 1;
        rc = random_aes_ctr(i, silent, 320, 320);
        if (rc) {
            printf("kat_aes_ctr failed with rc = %i\n", rc);
            return rc;
        } else
            printf("kat_aes_ctr finished successfuly\n");
        i++;
    }

    if (error_count)
        printf("%i testcases failed\n", error_count);
    else
        printf("All testcases finished successfully\n");

    return rc;
}
```

## AES with OFB mode example

```
/* This program is released under the Common Public License V1.0
 *
 * You should have received a copy of Common Public License V1.0 along with
 * with this program.
 */

/* Copyright IBM Corp. 2010, 2011 */
#include <fcntl.h>
#include <sys/errno.h>
#include <stdio.h>
#include <string.h>
#include <strings.h>
#include <stdlib.h>
#include "ica_api.h"

#define NR_TESTS 6
#define NR_RANDOM_TESTS 10000

/* OFB data - 1 for AES128 */
unsigned char NIST_KEY_OFB_E1[] = {
    0x2b, 0x7e, 0x15, 0x16, 0x28, 0xae, 0xd2, 0xa6,
    0xab, 0xf7, 0x15, 0x88, 0x09, 0xcf, 0x4f, 0x3c,
};

unsigned char NIST_IV_OFB_E1[] = {
    0x00, 0x01, 0x02, 0x03, 0x04, 0x05, 0x06, 0x07,
    0x08, 0x09, 0x0a, 0x0b, 0x0c, 0x0d, 0x0e, 0x0f,
};

unsigned char NIST_EXPECTED_IV_OFB_E1[] = {
    0x50, 0xfe, 0x67, 0xcc, 0x99, 0x6d, 0x32, 0xb6,
    0xda, 0x09, 0x37, 0xe9, 0x9b, 0xaf, 0xec, 0x60,
};

unsigned char NIST_TEST_DATA_OFB_E1[] = {
    0x6b, 0xc1, 0xbe, 0xe2, 0x2e, 0x40, 0x9f, 0x96,
    0xe9, 0x3d, 0x7e, 0x11, 0x73, 0x93, 0x17, 0x2a,
};

unsigned char NIST_TEST_RESULT_OFB_E1[] = {
    0x3b, 0x3f, 0xd9, 0x2e, 0xb7, 0x2d, 0xad, 0x20,
    0x33, 0x34, 0x49, 0xf8, 0xe8, 0x3c, 0xfb, 0x4a,
};

/* OFB data - 2 for AES128 */
unsigned char NIST_KEY_OFB_E2[] = {
    0x2b, 0x7e, 0x15, 0x16, 0x28, 0xae, 0xd2, 0xa6,
    0xab, 0xf7, 0x15, 0x88, 0x09, 0xcf, 0x4f, 0x3c,
};

unsigned char NIST_IV_OFB_E2[] = {
    0x50, 0xfe, 0x67, 0xcc, 0x99, 0x6d, 0x32, 0xb6,
    0xda, 0x09, 0x37, 0xe9, 0x9b, 0xaf, 0xec, 0x60,
};

unsigned char NIST_EXPECTED_IV_OFB_E2[] = {
    0xd9, 0xa4, 0xda, 0xda, 0x08, 0x92, 0x23, 0x9f,
    0x6b, 0x8b, 0x3d, 0x76, 0x80, 0xe1, 0x56, 0x74,
};

unsigned char NIST_TEST_DATA_OFB_E2[] = {
    0xae, 0x2d, 0x8a, 0x57, 0x1e, 0x03, 0xac, 0x9c,
    0x9e, 0xb7, 0x6f, 0xac, 0x45, 0xaf, 0x8e, 0x51,
};

unsigned char NIST_TEST_RESULT_OFB_E2[] = {
    0x77, 0x89, 0x50, 0x8d, 0x16, 0x91, 0x8f, 0x03,
    0xf5, 0x3c, 0x52, 0xda, 0xc5, 0x4e, 0xd8, 0x25,
};

/* OFB data - 3 - for AES192 */
unsigned char NIST_KEY_OFB_E3[] = {
    0x8e, 0x73, 0xb0, 0xf7, 0xda, 0x0e, 0x64, 0x52,
    0xc8, 0x10, 0xf3, 0x2b, 0x80, 0x90, 0x79, 0xe5,
    0x62, 0xf8, 0xea, 0xd2, 0x52, 0x2c, 0x6b, 0x7b,
};

unsigned char NIST_IV_OFB_E3[] = {
    0x00, 0x01, 0x02, 0x03, 0x04, 0x05, 0x06, 0x07,
    0x08, 0x09, 0x0a, 0x0b, 0x0c, 0x0d, 0x0e, 0x0f,
};

unsigned char NIST_EXPECTED_IV_OFB_E3[] = {
    0xa6, 0x09, 0xb3, 0x8d, 0xf3, 0xb1, 0x13, 0x3d,
    0xdd, 0xff, 0x27, 0x18, 0xba, 0x09, 0x56, 0x5e,
};

unsigned char NIST_TEST_DATA_OFB_E3[] = {
    0x6b, 0xc1, 0xbe, 0xe2, 0x2e, 0x40, 0x9f, 0x96,
    0xe9, 0x3d, 0x7e, 0x11, 0x73, 0x93, 0x17, 0x2a,
};

unsigned char NIST_TEST_RESULT_OFB_E3[] = {
    0xcd, 0xc8, 0x0d, 0x6f, 0xdd, 0xf1, 0x8c, 0xab,
    0x34, 0xc2, 0x59, 0x09, 0xc9, 0x9a, 0x41, 0x74,
};

/* OFB data - 4 - for AES192 */
unsigned char NIST_KEY_OFB_E4[] = {
    0x8e, 0x73, 0xb0, 0xf7, 0xda, 0x0e, 0x64, 0x52,
    0xc8, 0x10, 0xf3, 0x2b, 0x80, 0x90, 0x79, 0xe5,
    0x62, 0xf8, 0xea, 0xd2, 0x52, 0x2c, 0x6b, 0x7b,
};

unsigned char NIST_IV_OFB_E4[] = {
    0xa6, 0x09, 0xb3, 0x8d, 0xf3, 0xb1, 0x13, 0x3d,
    0xdd, 0xff, 0x27, 0x18, 0xba, 0x09, 0x56, 0x5e,
};

unsigned char NIST_EXPECTED_IV_OFB_E4[] = {
    0x52, 0xef, 0x01, 0xda, 0x52, 0x60, 0x2f, 0xe0,
    0x97, 0x5f, 0x78, 0xac, 0x84, 0xbf, 0x8a, 0x50,
};

unsigned char NIST_TEST_DATA_OFB_E4[] = {
    0xae, 0x2d, 0x8a, 0x57, 0x1e, 0x03, 0xac, 0x9c,
    0x9e, 0xb7, 0x6f, 0xac, 0x45, 0xaf, 0x8e, 0x51,
};

unsigned char NIST_TEST_RESULT_OFB_E4[] = {
    0xfc, 0xc2, 0x8b, 0x8d, 0x4c, 0x63, 0x83, 0x7c,
    0x09, 0xe8, 0x17, 0x00, 0xc1, 0x10, 0x04, 0x01,
};

/* OFB data 5 - for AES 256 */
unsigned char NIST_KEY_OFB_E5[] = {
    0x60, 0x3d, 0xeb, 0x10, 0x15, 0xca, 0x71, 0xbe,
    0x2b, 0x73, 0xae, 0xf0, 0x85, 0x7d, 0x77, 0x81,
    0x1f, 0x35, 0x2c, 0x07, 0x3b, 0x61, 0x08, 0xd7,
    0x2d, 0x98, 0x10, 0xa3, 0x09, 0x14, 0xdf, 0xf4,
};

unsigned char NIST_IV_OFB_E5[] = {
    0x00, 0x01, 0x02, 0x03, 0x04, 0x05, 0x06, 0x07,
    0x08, 0x09, 0x0a, 0x0b, 0x0c, 0x0d, 0x0e, 0x0f,
};

unsigned char NIST_EXPECTED_IV_OFB_E5[] = {
    0xb7, 0xbf, 0x3a, 0x5d, 0xf4, 0x39, 0x89, 0xdd,
    0x97, 0xf0, 0xfa, 0x97, 0xeb, 0xce, 0x2f, 0x4a,
};

unsigned char NIST_TEST_DATA_OFB_E5[] = {
    0x6b, 0xc1, 0xbe, 0xe2, 0x2e, 0x40, 0x9f, 0x96,
    0xe9, 0x3d, 0x7e, 0x11, 0x73, 0x93, 0x17, 0x2a,
};

unsigned char NIST_TEST_RESULT_OFB_E5[] = {
    0xdc, 0x7e, 0x84, 0xbf, 0xda, 0x79, 0x16, 0x4b,
    0x7e, 0xcd, 0x84, 0x86, 0x98, 0x5d, 0x38, 0x60,
};

/* OFB data 6 - for AES 256 */
unsigned char NIST_KEY_OFB_E6[] = {
    0x60, 0x3d, 0xeb, 0x10, 0x15, 0xca, 0x71, 0xbe,
    0x2b, 0x73, 0xae, 0xf0, 0x85, 0x7d, 0x77, 0x81,
    0x1f, 0x35, 0x2c, 0x07, 0x3b, 0x61, 0x08, 0xd7,
    0x2d, 0x98, 0x10, 0xa3, 0x09, 0x14, 0xdf, 0xf4,
};
```

```
unsigned char NIST_IV_OFB_E6[] = {
    0xb7, 0xbf, 0x3a, 0x5d, 0xf4, 0x39, 0x89, 0xdd,
    0x97, 0xf0, 0xfa, 0x97, 0xeb, 0xce, 0x2f, 0x4a,
};

unsigned char NIST_EXPECTED_IV_OFB_E6[] = {
    0xe1, 0xc6, 0x56, 0x30, 0x5e, 0xd1, 0xa7, 0xa6,
    0x56, 0x38, 0x05, 0x74, 0x6f, 0xe0, 0x3e, 0xdc,
};

unsigned char NIST_TEST_DATA_OFB_E6[] = {
    0xae, 0x2d, 0x8a, 0x57, 0x1e, 0x03, 0xac, 0x9c,
    0x9e, 0xb7, 0x6f, 0xac, 0x45, 0xaf, 0x8e, 0x51,
};

unsigned char NIST_TEST_RESULT_OFB_E6[] = {
    0x4f, 0xeb, 0xdc, 0x67, 0x40, 0xd2, 0x0b, 0x3a,
    0xc8, 0x8f, 0x6a, 0xd8, 0x2a, 0x4f, 0xb0, 0x8d,
};


void dump_array(unsigned char *ptr, unsigned int size)
{
    unsigned char *ptr_end;
    unsigned char *h;
    int i = 1;

    h = ptr;
    ptr_end = ptr + size;
    while (h < (unsigned char *)ptr_end) {
        printf("0x%02x ",(unsigned char ) *h);
        h++;
        if (i == 8) {
            printf("\n");
            i = 1;
        } else {
            ++i;
        }
    }
    printf("\n");
}

void dump_ofb_data(unsigned char *iv, unsigned int iv_length,
                   unsigned char *key, unsigned int key_length,
                   unsigned char *input_data, unsigned int data_length,
                   unsigned char *output_data)
{
    printf("IV \n");
    dump_array(iv, iv_length);
    printf("Key \n");
    dump_array(key, key_length);
    printf("Input Data\n");
    dump_array(input_data, data_length);
    printf("Output Data\n");
    dump_array(output_data, data_length);
}

void get_sizes(unsigned int *data_length, unsigned int *iv_length,
           unsigned int *key_length, unsigned int iteration)
{
    switch (iteration) {
        case 1:
            *data_length = sizeof(NIST_TEST_DATA_OFB_E1);
            *iv_length = sizeof(NIST_IV_OFB_E1);
            *key_length = sizeof(NIST_KEY_OFB_E1);
            break;
        case 2:
            *data_length = sizeof(NIST_TEST_DATA_OFB_E2);
            *iv_length = sizeof(NIST_IV_OFB_E2);
            *key_length = sizeof(NIST_KEY_OFB_E2);
            break;
        case 3:
            *data_length = sizeof(NIST_TEST_DATA_OFB_E3);
            *iv_length = sizeof(NIST_IV_OFB_E3);
            *key_length = sizeof(NIST_KEY_OFB_E3);
            break;
        case 4:
            *data_length = sizeof(NIST_TEST_DATA_OFB_E4);
            *iv_length = sizeof(NIST_IV_OFB_E4);
            *key_length = sizeof(NIST_KEY_OFB_E4);
            break;
        case 5:
            *data_length = sizeof(NIST_TEST_DATA_OFB_E5);
            *iv_length = sizeof(NIST_IV_OFB_E5);
            *key_length = sizeof(NIST_KEY_OFB_E5);
            break;
        case 6:
            *data_length = sizeof(NIST_TEST_DATA_OFB_E6);
            *iv_length = sizeof(NIST_IV_OFB_E6);
            *key_length = sizeof(NIST_KEY_OFB_E6);
            break;
    }

}

void load_test_data(unsigned char *data, unsigned int data_length,
            unsigned char *result,
            unsigned char *iv, unsigned char *expected_iv,
            unsigned int iv_length,
            unsigned char *key, unsigned int key_length,
            unsigned int iteration)
{
    switch (iteration) {
        case 1:
            memcpy(data, NIST_TEST_DATA_OFB_E1, data_length);
            memcpy(result, NIST_TEST_RESULT_OFB_E1, data_length);
            memcpy(iv, NIST_IV_OFB_E1, iv_length);
            memcpy(expected_iv, NIST_EXPECTED_IV_OFB_E1, iv_length);
            memcpy(key, NIST_KEY_OFB_E1, key_length);
            break;
        case 2:
            memcpy(data, NIST_TEST_DATA_OFB_E2, data_length);
            memcpy(result, NIST_TEST_RESULT_OFB_E2, data_length);
            memcpy(iv, NIST_IV_OFB_E2, iv_length);
            memcpy(expected_iv, NIST_EXPECTED_IV_OFB_E2, iv_length);
            memcpy(key, NIST_KEY_OFB_E2, key_length);
            break;
        case 3:
            memcpy(data, NIST_TEST_DATA_OFB_E3, data_length);
            memcpy(result, NIST_TEST_RESULT_OFB_E3, data_length);
            memcpy(iv, NIST_IV_OFB_E3, iv_length);
            memcpy(expected_iv, NIST_EXPECTED_IV_OFB_E3, iv_length);
            memcpy(key, NIST_KEY_OFB_E3, key_length);
            break;
        case 4:
            memcpy(data, NIST_TEST_DATA_OFB_E4, data_length);
            memcpy(result, NIST_TEST_RESULT_OFB_E4, data_length);
            memcpy(iv, NIST_IV_OFB_E4, iv_length);
            memcpy(expected_iv, NIST_EXPECTED_IV_OFB_E4, iv_length);
            memcpy(key, NIST_KEY_OFB_E4, key_length);
            break;
        case 5:
            memcpy(data, NIST_TEST_DATA_OFB_E5, data_length);
            memcpy(result, NIST_TEST_RESULT_OFB_E5, data_length);
            memcpy(iv, NIST_IV_OFB_E5, iv_length);
            memcpy(expected_iv, NIST_EXPECTED_IV_OFB_E5, iv_length);
            memcpy(key, NIST_KEY_OFB_E5, key_length);
            break;
        case 6:
            memcpy(data, NIST_TEST_DATA_OFB_E6, data_length);
            memcpy(result, NIST_TEST_RESULT_OFB_E6, data_length);
            memcpy(iv, NIST_IV_OFB_E6, iv_length);
            memcpy(expected_iv, NIST_EXPECTED_IV_OFB_E6, iv_length);
            memcpy(key, NIST_KEY_OFB_E6, key_length);
            break;
    }

}

int load_random_test_data(unsigned char *data, unsigned int data_length,
                   unsigned char *iv, unsigned int iv_length,
                   unsigned char *key, unsigned int key_length)
{
    int rc;
    rc = ica_random_number_generate(data_length, data);
    if (rc) {
        printf("ica_random_number_generate with rc = %i errnor = %i\n",
               rc, errno);
        return rc;
    }
    rc = ica_random_number_generate(iv_length, iv);
    if (rc) {
        printf("ica_random_number_generate with rc = %i errnor = %i\n",
               rc, errno);
        return rc;
    }
    rc = ica_random_number_generate(key_length, key);
    if (rc) {
        printf("ica_random_number_generate with rc = %i errnor = %i\n",
               rc, errno);
        return rc;
    }
    return rc;
}

int random_aes_ofb(int iteration, int silent, unsigned int data_length)
{
    int i;
    int rc = 0;
    unsigned int iv_length = sizeof(ica_aes_vector_t);
    unsigned int key_length = AES_KEY_LEN128;
    unsigned char iv[iv_length];
    unsigned char tmp_iv[iv_length];
    unsigned char input_data[data_length];
    unsigned char encrypt[data_length];
    unsigned char decrypt[data_length];
for (i = 0; i <= 2; i++) {

    unsigned char key[key_length];

    memset(encrypt, 0x00, data_length);
    memset(decrypt, 0x00, data_length);

    load_random_test_data(input_data, data_length, iv, iv_length, key,
                  key_length);
    memcpy(tmp_iv, iv, iv_length);
    printf("Test Parameters for iteration = %i\n", iteration);
    printf("key length = %i, data length = %i, iv length = %i\n",
           key_length, data_length, iv_length);

    rc = ica_aes_ofb(input_data, encrypt, data_length, key, key_length,
             tmp_iv, 1);
    if (rc) {
        printf("ica_aes_ofb encrypt failed with rc = %i\n", rc);
        dump_ofb_data(iv, iv_length, key, key_length, input_data,
                  data_length, encrypt);
    }
    if (!silent && !rc) {
        printf("Encrypt:\n");
        dump_ofb_data(iv, iv_length, key, key_length, input_data,
                  data_length, encrypt);
    }

    if (rc) {
        printf("AES OFB test exited after encryption\n");
        return rc;
    }

    memcpy(tmp_iv, iv, iv_length);

    rc = ica_aes_ofb(encrypt, decrypt, data_length, key, key_length,
             tmp_iv, 0);
    if (rc) {
        printf("ica_aes_ofb decrypt failed with rc = %i\n", rc);
        dump_ofb_data(iv, iv_length, key, key_length, encrypt,
                  data_length, decrypt);
        return rc;
    }


    if (!silent && !rc) {
        printf("Decrypt:\n");
        dump_ofb_data(iv, iv_length, key, key_length, encrypt,
                  data_length, decrypt);
    }

    if (memcmp(decrypt, input_data, data_length)) {
        printf("Decryption Result does not match the original data!\n");
        printf("Original data:\n");
        dump_array(input_data, data_length);
        printf("Decryption Result:\n");
        dump_array(decrypt, data_length);
        rc++;
        return rc;
    }
    key_length += 8;
```

```
}

    return rc;
}

int kat_aes_ofb(int iteration, int silent)
{
    unsigned int data_length;
    unsigned int iv_length;
    unsigned int key_length;

    get_sizes(&data_length, &iv_length, &key_length, iteration);

    printf("Test Parameters for iteration = %i\n", iteration);
    printf("key length = %i, data length = %i, iv length = %i\n",
           key_length, data_length, iv_length);

    unsigned char iv[iv_length];
    unsigned char tmp_iv[iv_length];
    unsigned char expected_iv[iv_length];
    unsigned char key[key_length];
    unsigned char input_data[data_length];
    unsigned char encrypt[data_length];
    unsigned char decrypt[data_length];
    unsigned char result[data_length];

    int rc = 0;

    load_test_data(input_data, data_length, result, iv, expected_iv,
               iv_length, key, key_length, iteration);
    memcpy(tmp_iv, iv, iv_length);

    rc = ica_aes_ofb(input_data, encrypt, data_length, key, key_length,
             tmp_iv, 1);
    if (rc) {
        printf("ica_aes_ofb encrypt failed with rc = %i\n", rc);
        dump_ofb_data(iv, iv_length, key, key_length, input_data,
                  data_length, encrypt);
    }
    if (!silent && !rc) {
        printf("Encrypt:\n");
        dump_ofb_data(iv, iv_length, key, key_length, input_data,
                  data_length, encrypt);
    }

    if (memcmp(result, encrypt, data_length)) {
        printf("Encryption Result does not match the known ciphertext!\n");
        printf("Expected data:\n");
        dump_array(result, data_length);
        printf("Encryption Result:\n");
        dump_array(encrypt, data_length);
        rc++;
    }

    if (memcmp(expected_iv, tmp_iv, iv_length)) {
        printf("Update of IV does not match the expected IV!\n");
        printf("Expected IV:\n");
        dump_array(expected_iv, iv_length);
        printf("Updated IV:\n");
        dump_array(tmp_iv, iv_length);
        printf("Original IV:\n");
        dump_array(iv, iv_length);
        rc++;
    }
    if (rc) {
        printf("AES OFB test exited after encryption\n");
        return rc;
    }

    memcpy(tmp_iv, iv, iv_length);
    rc = ica_aes_ofb(encrypt, decrypt, data_length, key, key_length,
             tmp_iv, 0);
    if (rc) {
        printf("ica_aes_ofb decrypt failed with rc = %i\n", rc);
        dump_ofb_data(iv, iv_length, key, key_length, encrypt,
                  data_length, decrypt);
        return rc;
    }


    if (!silent && !rc) {
        printf("Decrypt:\n");
        dump_ofb_data(iv, iv_length, key, key_length, encrypt,
                  data_length, decrypt);
    }

    if (memcmp(decrypt, input_data, data_length)) {
        printf("Decryption Result does not match the original data!\n");
        printf("Original data:\n");
        dump_array(input_data, data_length);
        printf("Decryption Result:\n");
        dump_array(decrypt, data_length);
        rc++;
    }
    return rc;
}

int main(int argc, char **argv)
{
    unsigned int silent = 0;
    if (argc > 1) {
        if (strstr(argv[1], "silent"))
            silent = 1;
    }
    int rc = 0;
    int error_count = 0;
    int iteration;
    unsigned int data_length = sizeof(ica_aes_vector_t);
    for(iteration = 1; iteration <= NR_TESTS; iteration++)    {
        rc = kat_aes_ofb(iteration, silent);
        if (rc) {
            printf("kat_aes_ofb failed with rc = %i\n", rc);
            error_count++;
        } else
            printf("kat_aes_ofb finished successfuly\n");

    }
    for(iteration = 1; iteration <= NR_RANDOM_TESTS; iteration++)    {
        int silent = 1;
        rc = random_aes_ofb(iteration, silent, data_length);
        if (rc) {
            printf("random_aes_ofb failed with rc = %i\n", rc);
            error_count++;
            goto out;
        } else
            printf("random_aes_ofb finished successfuly\n");
        data_length += sizeof(ica_aes_vector_t);
    }

out:
    if (error_count)
        printf("%i testcases failed\n", error_count);
    else
        printf("All testcases finished successfully\n");

    return rc;
}
```

## AES with XTS mode example

```
/* This program is released under the Common Public License V1.0
 *
 * You should have received a copy of Common Public License V1.0 along with
 * with this program.
 *
 * Copyright IBM Corp. 2016
 *
 */

#include <stdio.h>
#include <string.h>
#include <errno.h>

#include <ica_api.h>

#define AES_CIPHER_BLOCK_SIZE  16

/* This example uses a static keys. In real life you would
 * use real AES keys, which is negotiated between the
 * encrypting and the decrypting entity.
 *
 * Note: AES-128 key size is 16 bytes (AES_KEY_LEN128)
 */
unsigned char aes_xts_key1[] = {
    0x00, 0x01, 0x02, 0x03, 0x04, 0x05, 0x06, 0x07,
    0x08, 0x09, 0x0A, 0x0B, 0x0C, 0x0D, 0x0E, 0x0F,
};
unsigned char aes_xts_key2[] = {
    0x10, 0x11, 0x12, 0x13, 0x14, 0x15, 0x16, 0x17,
    0x18, 0x19, 0x1A, 0x1B, 0x1C, 0x1D, 0x1E, 0x1F,
};

/* This is the plain data, you want to encrypt. For the
 * encryption mode used in this example, it is necessary,
 * that the length of the encrypted data is at least as
 * large as the AES cipher block size (AES_CIPHER_BLOCK_SIZE),
 * but it does not have to be a multiple of the cipher block size.
 */
unsigned char plain_data[] = {
    0x55, 0x73, 0x69, 0x6e, 0x67, 0x20, 0x6c, 0x69,
    0x62, 0x69, 0x63, 0x61, 0x20, 0x77, 0x69, 0x74,
    0x68, 0x20, 0x41, 0x45, 0x53, 0x2d, 0x58, 0x54,
    0x53, 0x20, 0x69, 0x73, 0x20, 0x73, 0x6d, 0x61,
    0x72, 0x74, 0x20, 0x61, 0x6e, 0x64, 0x20, 0x65,
    0x61, 0x73, 0x79, 0x21, 0x00
};

/* Prints hex values to standard out. */
static void dump_data(unsigned char *data, unsigned long length);
/* Prints a description of the return value to standard out. */
static int handle_ica_error(int rc);

int main(char **argv, int argc)
{
    int rc;

    /* This is the AES XTS tweak value.
     * We are generating it per random number generator. In real life
     * you would use an tweak value which is negotiated between the
     * encrypting and the decrypting entity.
     */
    unsigned char random_tweak_value[AES_CIPHER_BLOCK_SIZE];

    /* Since libica function ica_aes_xts updates the tweak value
     * we let ica_aes_xts work on a copy of the generated tweak
     * value. We will need the original tweak value for decrypting
     * the data later on.
     */
    unsigned char tweak_value[AES_CIPHER_BLOCK_SIZE];

    unsigned char cipher_data[sizeof(plain_data)];
    unsigned char decrypt_data[sizeof(plain_data)];

    /* Generate the tweak value by random */
    rc = ica_random_number_generate(sizeof(random_tweak_value),
                                    random_tweak_value);

    /* Error handling (if necessary). */
    if (rc)
        return handle_ica_error(rc);

    /* Dump keys, tweak value and plain data to standard output, just for
     * a visual control.
     */
    printf("AES key1:\n");
    dump_data(aes_xts_key1, sizeof(aes_xts_key1));
    printf("AES key2:\n");
    dump_data(aes_xts_key2, sizeof(aes_xts_key2));
    printf("TWEAK:\n");
    dump_data(random_tweak_value, sizeof(random_tweak_value));
    printf("plain data:\n");
    dump_data(plain_data, sizeof(plain_data));

    /* Copy the generated tweak value so that we still
     * have the original one available after the call to ica_aes_xts.
     */
    memcpy(tweak_value,random_tweak_value,sizeof(tweak_value));

    /* Encrypt plain data to cipher data, using libica API.
     */
    rc = ica_aes_xts(plain_data, cipher_data, sizeof(plain_data),
             aes_xts_key1, aes_xts_key2, AES_KEY_LEN128, tweak_value,
             ICA_ENCRYPT);

    /* Error handling (if necessary). */
    if (rc)
        return handle_ica_error(rc);

    /* Dump encrypted data.
     */
    printf("encrypted data:\n");
    dump_data(cipher_data, sizeof(plain_data));

    /* Get the original tweak value, because ica_aes_xts
     * has modified the tweak_value variable on encryption.
     */
    memcpy(tweak_value,random_tweak_value,sizeof(tweak_value));

    /* Decrypt cipher data to decrypted data, using libica API.
     * Note: The same AES keys and tweak value must be used for
     * encryption and decryption.
     */
    rc = ica_aes_xts(cipher_data, decrypt_data, sizeof(plain_data),
             aes_xts_key1, aes_xts_key2, AES_KEY_LEN128, tweak_value,
             ICA_DECRYPT);

    /* Error handling (if necessary). */
    if (rc)
        return handle_ica_error(rc);

    /* Dump decrypted data.
     * Note: Please compare output with the plain data, they are the same.
     */
    printf("decrypted data:\n");
    dump_data(decrypt_data, sizeof(plain_data));

    /* Surprise... :-)
     * Note: The following will only work in this example!
     */
    printf("%s\n", decrypt_data);
}

static void dump_data(unsigned char *data, unsigned long length)
{
    unsigned char *ptr;
    int i;

    for (ptr = data, i = 1; ptr < (data+length); ptr++, i++) {
        printf("0x%02x ", *ptr);
        if ((i % AES_CIPHER_BLOCK_SIZE) == 0)
            printf("\n");
    }
    if (i % AES_CIPHER_BLOCK_SIZE)
        printf("\n");
}

static int handle_ica_error(int rc)
{
    switch (rc) {
    case 0:
        printf("OK\n");
        break;
    case EINVAL:
        printf("Incorrect parameter.\n");
        break;
    case EPERM:
        printf("Operation not permitted by Hardware (CPACF).\n");
        break;
    case EIO:
        printf("I/O error.\n");
        break;
    default:
        printf("unknown error.\n");
    }

    return rc;
}
```

## AES with CBC mode example

```
/* This program is released under the Common Public License V1.0
 *
 * You should have received a copy of Common Public License V1.0 along with
 * with this program.
 *
 * Copyright IBM Corp. 2016
 *
 */

#include <stdio.h>
#include <string.h>
#include <errno.h>

#include <ica_api.h>

#define AES_CIPHER_BLOCK_SIZE  16

/* This example uses a static key. In real life you would
 * use your real AES key, which is negotiated between the
 * encrypting and the decrypting entity.
 *
 * Note: AES-128 key size is 16 bytes (AES_KEY_LEN128)
 */
unsigned char aes_key[] = {
    0x00, 0x01, 0x02, 0x03, 0x04, 0x05, 0x06, 0x07,
    0x08, 0x09, 0x0A, 0x0B, 0x0C, 0x0D, 0x0E, 0x0F,
};

/* This is the plain data, you want to encrypt. For the
 * encryption mode used in this example, it is necessary,
 * that the length of the encrypted data is a multiple of
 * the AES cipher block size (AES_CIPHER_BLOCK_SIZE).
 */
unsigned char plain_data[] = {
    0x55, 0x73, 0x69, 0x6e, 0x67, 0x20, 0x6c, 0x69,
    0x62, 0x69, 0x63, 0x61, 0x20, 0x69, 0x73, 0x20,
    0x73, 0x6d, 0x61, 0x72, 0x74, 0x20, 0x61, 0x6e,
    0x64, 0x20, 0x65, 0x61, 0x73, 0x79, 0x21, 0x00,
};

/* Prints hex values to standard out. */
static void dump_data(unsigned char *data, unsigned long length);
/* Prints a description of the return value to standard out. */
static int handle_ica_error(int rc);

int main(char **argv, int argc)
{
    int rc;

    /* This is the initialization vector. The initialization vector
     * is of the same size as the cipher block (AES_CIPHER_BLOCK_SIZE).
     * We are generating it per random number generator. In real life
     * you would use an initialization vector which is negotiated
     * between the encrypting and the decrypting entity.
     */
    unsigned char random_iv[AES_CIPHER_BLOCK_SIZE];

    /* Since libica function ica_aes_cbc updates the initialization
     * vector, we let ica_aes_cbc work on a copy of the generated
     * initialization vector. We will need the original initialization
     * vector for decrypting the data later on.
     */
    unsigned char iv[AES_CIPHER_BLOCK_SIZE];

    unsigned char cipher_data[sizeof(plain_data)];
    unsigned char decrypt_data[sizeof(plain_data)];

    /* Generate the initialization vector by random */
    rc = ica_random_number_generate(sizeof(random_iv), random_iv);

    /* Error handling (if necessary). */
    if (rc)
        return handle_ica_error(rc);

    /* Dump key, iv and plain data to standard output, just for
     * a visual control.
     */
    printf("AES key:\n");
    dump_data(aes_key, sizeof(aes_key));
    printf("IV:\n");
    dump_data(random_iv, sizeof(random_iv));
    printf("plain data:\n");
    dump_data(plain_data, sizeof(plain_data));

    /* Copy the generated initialization vector so that we still
     * have the original one available after the call to ica_aes_cbc.
     */
    memcpy(iv,random_iv,sizeof(iv));

    /* Encrypt plain data to cipher data, using libica API.
     */
    rc = ica_aes_cbc(plain_data, cipher_data, sizeof(plain_data),
             aes_key, AES_KEY_LEN128, iv,
             ICA_ENCRYPT);

    /* Error handling (if necessary). */
    if (rc)
        return handle_ica_error(rc);

    /* Dump encrypted data. */
    printf("encrypted data:\n");
    dump_data(cipher_data, sizeof(plain_data));

    /* Get the original initialization vector, because ica_aes_cbc
     * has modified the iv variable on encryption.
     */
    memcpy(iv,random_iv,sizeof(iv));

    /* Decrypt cipher data to decrypted data, using libica API.
     * Note: The same AES key and IV must be used for encryption and
     * decryption.
     */
    rc = ica_aes_cbc(cipher_data, decrypt_data, sizeof(plain_data),
             aes_key, AES_KEY_LEN128, iv,
             ICA_DECRYPT);

    /* Error handling (if necessary). */
    if (rc)
        return handle_ica_error(rc);

    /* Dump decrypted data.
     * Note: Please compare output with the plain data, they are the same.
     */
    printf("decrypted data:\n");
    dump_data(decrypt_data, sizeof(plain_data));

    /* Surprise... :-)
     * Note: The following will only work in this example!
     */
    printf("%s\n", decrypt_data);
}

static void dump_data(unsigned char *data, unsigned long length)
{
    unsigned char *ptr;
    int i;

    for (ptr = data, i = 1; ptr < (data+length); ptr++, i++) {
        printf("0x%02x ", *ptr);
        if ((i % AES_CIPHER_BLOCK_SIZE) == 0)
            printf("\n");
    }
    if (i % AES_CIPHER_BLOCK_SIZE)
        printf("\n");
}

static int handle_ica_error(int rc)
{
    switch (rc) {
    case 0:
        printf("OK\n");
        break;
    case EINVAL:
        printf("Incorrect parameter.\n");
        break;
    case EPERM:
        printf("Operation not permitted by Hardware (CPACF).\n");
        break;
    case EIO:
        printf("I/O error.\n");
        break;
    default:
        printf("unknown error.\n");
    }

    return rc;
}
```

## AES with GCM mode example

```
/* This program is released under the Common Public License V1.0
 *
 * You should have received a copy of Common Public License V1.0 along with
 * with this program.
 *
 * Copyright IBM Corp. 2016
 *
 */

#include <stdio.h>
#include <string.h>
#include <errno.h>

#include <ica_api.h>

#define AES_CIPHER_BLOCK_SIZE  16

/* This example uses a static key. In real life you would
 * use your real AES key, which is negotiated between the
 * encrypting and the decrypting entity.
 *
 * Note: AES-128 key size is 16 bytes (AES_KEY_LEN128)
 */
unsigned char aes_key[] = {
    0x00, 0x01, 0x02, 0x03, 0x04, 0x05, 0x06, 0x07,
    0x08, 0x09, 0x0A, 0x0B, 0x0C, 0x0D, 0x0E, 0x0F
};

/* This is the plain data, you want to encrypt.
 */
unsigned char plain_data[] = {
    0x55, 0x73, 0x69, 0x6e, 0x67, 0x20, 0x6c, 0x69,
    0x62, 0x69, 0x63, 0x61, 0x20, 0x69, 0x73, 0x20,
    0x73, 0x6d, 0x61, 0x72, 0x74, 0x20, 0x61, 0x6e,
    0x64, 0x20, 0x65, 0x61, 0x73, 0x79, 0x21, 0x00
};

/* This is the initialization vector. The initialization vector
 * size must be greater than 0 and less than $2^{61}$. A length of
 * 12 is recommended.
 */
unsigned char iv[12] = {
    0x00, 0x01, 0x02, 0x03, 0x04, 0x05, 0x06, 0x07,
    0x08, 0x09, 0x0A, 0x0B
};

/* This is additional authenticated data. It is subject to the
 * message authentication code computation, but is not encrypted.
 */
unsigned char aad[] = {
    0x10, 0x11, 0x12, 0x13, 0x14, 0x15, 0x16, 0x17,
    0x18, 0x19, 0x1A, 0x1B, 0x1C, 0x1D, 0x1E, 0x1F
};

/* Prints hex values to standard out. */
static void dump_data(unsigned char *data, unsigned long length);
/* Prints a description of the return value to standard out. */
static int handle_ica_error(int rc);

int main(char **argv, int argc)
{
    int rc;

    /* This is a buffer for the message authentication code (tag) for
     * the additional authenticated data in aad and the plain text.
     * Note: The authentication strength depends on the length of the
     *       authentication tag
     */
    unsigned char tag[16];

    unsigned char cipher_data[sizeof(plain_data)];
    unsigned char decrypt_data[sizeof(plain_data)];

    /* Dump key, iv, aad and plain data to standard output, just for
     * a visual control.
     */
    printf("AES key:\n");
    dump_data(aes_key, sizeof(aes_key));
    printf("IV:\n");
    dump_data(iv, sizeof(iv));
    printf("AAD:\n");
    dump_data(aad, sizeof(aad));
    printf("plain data:\n");
    dump_data(plain_data, sizeof(plain_data));

    /* Encrypt plain data to cipher data, using libica API.
     * This will also compute the authetication code (tag) from
     * the plain data and the additional authenticated data.
     */
    rc = ica_aes_gcm(plain_data, sizeof(plain_data), cipher_data,
                iv, sizeof(iv),
                aad, sizeof(aad),
                tag, sizeof(tag),
                aes_key, AES_KEY_LEN128,
                ICA_ENCRYPT);

    /* Error handling (if necessary). */
    if (rc)
        return handle_ica_error(rc);

    /* Dump encrypted data.
     */
    printf("encrypted data:\n");
    dump_data(cipher_data, sizeof(plain_data));
    printf("Authetication code:\n");
    dump_data(tag, sizeof(tag));

    /* Decrypt cipher data to decrypted data, using libica API.
     * Note: The same AES key, IV and AAD must be used for encryption and
     * decryption. The authentication code (tag) is verified against the
     * decrypted data and the additional authenticated data. If the
     * authentication code does not match, EFAULT is returned.
     */
    rc = ica_aes_gcm(decrypt_data, sizeof(plain_data), cipher_data,
                iv, sizeof(iv),
                aad, sizeof(aad),
                tag, sizeof(tag),
                aes_key, AES_KEY_LEN128,
                ICA_DECRYPT);

    /* Error handling (if necessary). */
    if (rc)
        return handle_ica_error(rc);

    /* Dump decrypted data.
     * Note: Please compare output with the plain data, they are the same.
     */
    printf("decrypted data:\n");
    dump_data(decrypt_data, sizeof(plain_data));

    /* Surprise... :-)
     * Note: The following will only work in this example!
     */
    printf("%s\n", decrypt_data);


 return rc;
}

static void dump_data(unsigned char *data, unsigned long length)
{
    unsigned char *ptr;
    int i;

    for (ptr = data, i = 1; ptr < (data+length); ptr++, i++) {
        printf("0x%02x ", *ptr);
        if ((i % AES_CIPHER_BLOCK_SIZE) == 0)
            printf("\n");
    }
    if (i % AES_CIPHER_BLOCK_SIZE)
        printf("\n");
}

static int handle_ica_error(int rc)
{
    switch (rc) {
    case 0:
        printf("OK\n");
        break;
    case EINVAL:
        printf("Incorrect parameter.\n");
        break;
    case EPERM:
        printf("Operation not permitted by Hardware (CPACF).\n");
        break;
    case EIO:
        printf("I/O error.\n");
        break;
    case EFAULT:
        printf("The verification of the message authentication code has failed.\n");
        break;
    default:
        printf("unknown error.\n");
    }

    return rc;
}
```

## CMAC example

```
/* This program is released under the Common Public License V1.0
 *
 * You should have received a copy of Common Public License V1.0 along with
 * with this program.
 */

/* Copyright IBM Corp. 2010, 2011 */
#include <fcntl.h>
#include <sys/errno.h>
#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include "ica_api.h"

#define BYTE 8

#define NUM_TESTS 12

unsigned int key_length[12] = {16, 16, 16, 16, 24, 24, 24, 24, 32, 32, 32,
                32};
unsigned char key[12][32] = {{
    0x2b, 0x7e, 0x15, 0x16, 0x28, 0xae, 0xd2, 0xa6, 0xab, 0xf7, 0x15,
    0x88, 0x09, 0xcf, 0x4f, 0x3c},{
    0x2b, 0x7e, 0x15, 0x16, 0x28, 0xae, 0xd2, 0xa6, 0xab, 0xf7, 0x15,
    0x88, 0x09, 0xcf, 0x4f, 0x3c},{
    0x2b, 0x7e, 0x15, 0x16, 0x28, 0xae, 0xd2, 0xa6, 0xab, 0xf7, 0x15,
    0x88, 0x09, 0xcf, 0x4f, 0x3c},{
    0x2b, 0x7e, 0x15, 0x16, 0x28, 0xae, 0xd2, 0xa6, 0xab, 0xf7, 0x15,
    0x88, 0x09, 0xcf, 0x4f, 0x3c},{
    0x8e, 0x73, 0xb0, 0xf7, 0xda, 0x0e, 0x64, 0x52, 0xc8, 0x10 ,0xf3,
    0x2b, 0x80, 0x90, 0x79, 0xe5, 0x62, 0xf8, 0xea, 0xd2, 0x52, 0x2c,
    0x6b, 0x7b},{
    0x8e, 0x73, 0xb0, 0xf7, 0xda, 0x0e, 0x64, 0x52, 0xc8, 0x10 ,0xf3,
    0x2b, 0x80, 0x90, 0x79, 0xe5, 0x62, 0xf8, 0xea, 0xd2, 0x52, 0x2c,
    0x6b, 0x7b},{
    0x8e, 0x73, 0xb0, 0xf7, 0xda, 0x0e, 0x64, 0x52, 0xc8, 0x10 ,0xf3,
    0x2b, 0x80, 0x90, 0x79, 0xe5, 0x62, 0xf8, 0xea, 0xd2, 0x52, 0x2c,
    0x6b, 0x7b},{
    0x8e, 0x73, 0xb0, 0xf7, 0xda, 0x0e, 0x64, 0x52, 0xc8, 0x10 ,0xf3,
    0x2b, 0x80, 0x90, 0x79, 0xe5, 0x62, 0xf8, 0xea, 0xd2, 0x52, 0x2c,
    0x6b, 0x7b},{
    0x60, 0x3d, 0xeb, 0x10, 0x15, 0xca, 0x71, 0xbe, 0x2b, 0x73, 0xae,
    0xf0, 0x85, 0x7d, 0x77, 0x81, 0x1f, 0x35, 0x2c, 0x07, 0x3b, 0x61,
    0x08, 0xd7, 0x2d, 0x98, 0x10, 0xa3, 0x09, 0x14, 0xdf, 0xf4},{
    0x60, 0x3d, 0xeb, 0x10, 0x15, 0xca, 0x71, 0xbe, 0x2b, 0x73, 0xae,
    0xf0, 0x85, 0x7d, 0x77, 0x81, 0x1f, 0x35, 0x2c, 0x07, 0x3b, 0x61,
    0x08, 0xd7, 0x2d, 0x98, 0x10, 0xa3, 0x09, 0x14, 0xdf, 0xf4},{
    0x60, 0x3d, 0xeb, 0x10, 0x15, 0xca, 0x71, 0xbe, 0x2b, 0x73, 0xae,
    0xf0, 0x85, 0x7d, 0x77, 0x81, 0x1f, 0x35, 0x2c, 0x07, 0x3b, 0x61,
    0x08, 0xd7, 0x2d, 0x98, 0x10, 0xa3, 0x09, 0x14, 0xdf, 0xf4},{
    0x60, 0x3d, 0xeb, 0x10, 0x15, 0xca, 0x71, 0xbe, 0x2b, 0x73, 0xae,
    0xf0, 0x85, 0x7d, 0x77, 0x81, 0x1f, 0x35, 0x2c, 0x07, 0x3b, 0x61,
    0x08, 0xd7, 0x2d, 0x98, 0x10, 0xa3, 0x09, 0x14, 0xdf, 0xf4}
};

unsigned char last_block[3][16] = {{
    0x7d, 0xf7, 0x6b, 0x0c, 0x1a, 0xb8, 0x99, 0xb3, 0x3e, 0x42, 0xf0,
    0x47, 0xb9, 0x1b, 0x54, 0x6f},{
    0x22, 0x45, 0x2d, 0x8e, 0x49, 0xa8, 0xa5, 0x93, 0x9f, 0x73, 0x21,
    0xce, 0xea, 0x6d, 0x51, 0x4b},{
    0xe5, 0x68, 0xf6, 0x81, 0x94, 0xcf, 0x76, 0xd6, 0x17, 0x4d, 0x4c,
    0xc0, 0x43, 0x10, 0xa8, 0x54}
};

unsigned long mlen[12] = { 0, 16, 40, 64, 0,16, 40, 64, 0, 16, 40, 64};
unsigned char message[12][512] = {{
    0x00},{
    0x6b, 0xc1, 0xbe, 0xe2, 0x2e, 0x40, 0x9f, 0x96, 0xe9, 0x3d, 0x7e,
    0x11, 0x73, 0x93, 0x17, 0x2a},{
    0x6b, 0xc1, 0xbe, 0xe2, 0x2e, 0x40, 0x9f, 0x96, 0xe9, 0x3d, 0x7e,
    0x11, 0x73, 0x93, 0x17, 0x2a, 0xae, 0x2d, 0x8a, 0x57, 0x1e, 0x03,
    0xac, 0x9c, 0x9e, 0xb7, 0x6f, 0xac, 0x45, 0xaf ,0x8e, 0x51, 0x30,
    0xc8, 0x1c, 0x46, 0xa3, 0x5c, 0xe4, 0x11},{
    0x6b, 0xc1, 0xbe, 0xe2, 0x2e, 0x40, 0x9f, 0x96, 0xe9, 0x3d, 0x7e,
    0x11, 0x73, 0x93, 0x17, 0x2a, 0xae, 0x2d, 0x8a, 0x57, 0x1e, 0x03,
    0xac, 0x9c, 0x9e, 0xb7, 0x6f, 0xac, 0x45, 0xaf, 0x8e, 0x51, 0x30,
    0xc8, 0x1c, 0x46, 0xa3, 0x5c, 0xe4, 0x11, 0xe5, 0xfb, 0xc1, 0x19,
    0x1a, 0x0a, 0x52, 0xef, 0xf6, 0x9f, 0x24, 0x45, 0xdf, 0x4f, 0x9b,
    0x17, 0xad, 0x2b, 0x41, 0x7b, 0xe6, 0x6c, 0x37, 0x10},{
    0x00},{
    0x6b, 0xc1, 0xbe, 0xe2, 0x2e, 0x40, 0x9f, 0x96, 0xe9, 0x3d, 0x7e,
    0x11, 0x73, 0x93, 0x17, 0x2a},{
    0x6b, 0xc1, 0xbe, 0xe2, 0x2e, 0x40, 0x9f, 0x96, 0xe9, 0x3d, 0x7e,
    0x11, 0x73, 0x93, 0x17, 0x2a, 0xae, 0x2d, 0x8a, 0x57, 0x1e, 0x03,
    0xac, 0x9c, 0x9e, 0xb7, 0x6f, 0xac, 0x45, 0xaf ,0x8e, 0x51, 0x30,
    0xc8, 0x1c, 0x46, 0xa3, 0x5c, 0xe4, 0x11},{
    0x6b, 0xc1, 0xbe, 0xe2, 0x2e, 0x40, 0x9f, 0x96, 0xe9, 0x3d, 0x7e,
    0x11, 0x73, 0x93, 0x17, 0x2a, 0xae, 0x2d, 0x8a, 0x57, 0x1e, 0x03,
    0xac, 0x9c, 0x9e, 0xb7, 0x6f, 0xac, 0x45, 0xaf, 0x8e, 0x51, 0x30,
    0xc8, 0x1c, 0x46, 0xa3, 0x5c, 0xe4, 0x11, 0xe5, 0xfb, 0xc1, 0x19,
    0x1a, 0x0a, 0x52, 0xef, 0xf6, 0x9f, 0x24, 0x45, 0xdf, 0x4f, 0x9b,
    0x17, 0xad, 0x2b, 0x41, 0x7b, 0xe6, 0x6c, 0x37, 0x10},{
    0x00},{
    0x6b, 0xc1, 0xbe, 0xe2, 0x2e, 0x40, 0x9f, 0x96, 0xe9, 0x3d, 0x7e,
    0x11, 0x73, 0x93, 0x17, 0x2a},{
    0x6b, 0xc1, 0xbe, 0xe2, 0x2e, 0x40, 0x9f, 0x96, 0xe9, 0x3d, 0x7e,
    0x11, 0x73, 0x93, 0x17, 0x2a, 0xae, 0x2d, 0x8a, 0x57, 0x1e, 0x03,
    0xac, 0x9c, 0x9e, 0xb7, 0x6f, 0xac, 0x45, 0xaf ,0x8e, 0x51, 0x30,
    0xc8, 0x1c, 0x46, 0xa3, 0x5c, 0xe4, 0x11},{
    0x6b, 0xc1, 0xbe, 0xe2, 0x2e, 0x40, 0x9f, 0x96, 0xe9, 0x3d, 0x7e,
    0x11, 0x73, 0x93, 0x17, 0x2a, 0xae, 0x2d, 0x8a, 0x57, 0x1e, 0x03,
    0xac, 0x9c, 0x9e, 0xb7, 0x6f, 0xac, 0x45, 0xaf, 0x8e, 0x51, 0x30,
    0xc8, 0x1c, 0x46, 0xa3, 0x5c, 0xe4, 0x11, 0xe5, 0xfb, 0xc1, 0x19,
    0x1a, 0x0a, 0x52, 0xef, 0xf6, 0x9f, 0x24, 0x45, 0xdf, 0x4f, 0x9b,
    0x17, 0xad, 0x2b, 0x41, 0x7b, 0xe6, 0x6c, 0x37, 0x10}
};

unsigned char expected_cmac[12][16] = {{
    0xbb, 0x1d, 0x69, 0x29, 0xe9, 0x59, 0x37, 0x28, 0x7f, 0xa3, 0x7d,
    0x12, 0x9b, 0x75, 0x67, 0x46},{
    0x07, 0x0a, 0x16, 0xb4, 0x6b, 0x4d, 0x41, 0x44, 0xf7, 0x9b, 0xdd,
    0x9d, 0xd0, 0x4a, 0x28, 0x7c},{
    0xdf, 0xa6, 0x67, 0x47, 0xde, 0x9a, 0xe6, 0x30, 0x30, 0xca, 0x32,
    0x61, 0x14, 0x97, 0xc8, 0x27},{
    0x51, 0xf0, 0xbe, 0xbf, 0x7e, 0x3b, 0x9d, 0x92, 0xfc, 0x49, 0x74,
    0x17, 0x79, 0x36, 0x3c, 0xfe},{
    0xd1, 0x7d, 0xdf, 0x46, 0xad, 0xaa, 0xcd, 0xe5, 0x31, 0xca, 0xc4,
    0x83, 0xde, 0x7a, 0x93, 0x67},{
    0x9e, 0x99, 0xa7, 0xbf, 0x31, 0xe7, 0x10, 0x90, 0x06, 0x62, 0xf6,
    0x5e, 0x61, 0x7c, 0x51, 0x84},{
    0x8a, 0x1d, 0xe5, 0xbe, 0x2e, 0xb3, 0x1a, 0xad, 0x08, 0x9a, 0x82,
    0xe6, 0xee, 0x90, 0x8b, 0x0e},{
    0xa1, 0xd5, 0xdf, 0x0e, 0xed, 0x79, 0x0f, 0x79, 0x4d, 0x77, 0x58,
    0x96, 0x59, 0xf3, 0x9a, 0x11},{
    0x02, 0x89, 0x62, 0xf6, 0x1b, 0x7b, 0xf8, 0x9e, 0xfc, 0x6b, 0x55,
    0x1f, 0x46, 0x67, 0xd9, 0x83},{
    0x28, 0xa7, 0x02, 0x3f, 0x45, 0x2e, 0x8f, 0x82, 0xbd, 0x4b, 0xf2,
    0x8d, 0x8c, 0x37, 0xc3, 0x5c},{
    0xaa, 0xf3, 0xd8, 0xf1, 0xde, 0x56, 0x40, 0xc2, 0x32, 0xf5, 0xb1,
    0x69, 0xb9, 0xc9, 0x11, 0xe6},{
```

```
    0xe1, 0x99, 0x21, 0x90, 0x54, 0x9f, 0x6e, 0xd5, 0x69, 0x6a, 0x2c,
    0x05, 0x6c, 0x31, 0x54, 0x10}
};

unsigned int i = 0;

void dump_array(unsigned char *ptr, unsigned int size)
{
    unsigned char *ptr_end;
    unsigned char *h;
    int i = 1, trunc = 0;
    int maxsize = 2000;

    puts("Dump:");

    if (size > maxsize) {
        trunc = size - maxsize;
        size = maxsize;
    }
    h = ptr;
    ptr_end = ptr + size;
    while (h < ptr_end) {
        printf("0x%02x ", *h);
        h++;
        if (i == 16) {
            if (h != ptr_end)
            printf("\n");
            i = 1;
        } else {
            ++i;
        }
    }
    printf("\n");
    if (trunc > 0)
    printf("... %d bytes not printed\n", trunc);
}
unsigned char *cmac;
unsigned int cmac_length = 16;

int api_cmac_test(void)
{
    printf("Test of CMAC api\n");
    int rc = 0;
    for (i = 0 ; i < NUM_TESTS; i++) {
        if (!(cmac = malloc(cmac_length)))
            return EINVAL;
        memset(cmac, 0, cmac_length);
        rc = (ica_aes_cmac(message[i], mlen[i],
                   cmac, cmac_length,
                   key[i], key_length[i],
                   ICA_ENCRYPT));
        if (rc) {
            printf("ica_aes_cmac generate failed with errno %d (0x%x)."
                "\n",rc,rc);
            return rc;
        }
        if (memcmp(cmac, expected_cmac[i], cmac_length) != 0) {
            printf("This does NOT match the known result. "
                "Testcase %i failed\n",i);
            printf("\nOutput MAC for test %d:\n", i);
            dump_array((unsigned char *)cmac, cmac_length);
            printf("\nExpected MAC for test %d:\n", i);
            dump_array((unsigned char *)expected_cmac[i], 16);
            free(cmac);
            return 1;
        }
        printf("Expected MAC has been generated.\n");
        rc = (ica_aes_cmac(message[i], mlen[i],
                   cmac, cmac_length,
                   key[i], key_length[i],
                   ICA_DECRYPT));
        if (rc) {
            printf("ica_aes_cmac verify failed with errno %d (0x%x).\n",
                rc, rc);
            free(cmac);
            return rc;
        }
        free(cmac);
        if (! rc )
            printf("MAC was successful verified. testcase %i "
                "succeeded\n",i);
        else {
            printf("MAC verification failed for testcase %i "
                "with RC=%i\n",i,rc);
            return rc;
        }
    }
    return 0;
}

int main(int argc, char **argv)
{
    int rc = 0;

    rc = api_cmac_test();
    if (rc) {
        printf("api_cmac_test failed with rc = %i\n", rc);
        return rc;
    }
    printf("api_cmac_test was succesful\n");
    return 0;
}
```

## ECDSA example

```
/* This program is released under the Common Public License V1.0
 *
 * You should have received a copy of Common Public License V1.0 along with
 * with this program.
 *
 * Copyright IBM Corp. 2018
 */
#include <errno.h>
#include <openssl/crypto.h>
#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include <sys/time.h>

#include <openssl/opensslconf.h>
#ifdef OPENSSL_FIPS
#include <openssl/fips.h>
#endif /* OPENSSL_FIPS */

#include "ica_api.h"
#include "testcase.h"
#include <openssl/obj_mac.h>

#define MAX_ECC_PRIV_SIZE        66 /* 521 bits */
#define MAX_ECDSA_SIG_SIZE        2*MAX_ECC_PRIV_SIZE

static unsigned char hash[] = {
    0x00, 0x01, 0x02, 0x03, 0x04, 0x05, 0x06, 0x07,
    0x08, 0x09, 0x0a, 0x0b, 0x0c, 0x0d, 0x0e, 0x0f,
    0x10, 0x11, 0x12, 0x13,
};

int main(int argc, char **argv)
{
    ica_adapter_handle_t adapter_handle;
    unsigned int rc;
    unsigned char signature[MAX_ECDSA_SIG_SIZE];
    unsigned int privlen = 0;
    unsigned int hash_length = 20;
    unsigned int nid = NID_X9_62_prime256v1;
    ICA_EC_KEY *eckey;


    rc = ica_open_adapter(&adapter_handle);
    if (rc != 0) {
        V_(printf("ica_open_adapter failed and returned %d (0x%x).\n", rc, rc));
    }

    eckey = ica_ec_key_new(nid, &privlen);
    if (!eckey) {
        printf("Unsupported curve.\n");
        return rc;
    }

    rc = ica_ec_key_generate(adapter_handle, eckey);
    if (rc) {
        printf("EC key for curve %i could not be generated, rc=%i.\n", nid, rc);
        return rc;
    }

    rc = ica_ecdsa_sign(adapter_handle, eckey, hash, hash_length,
                    signature, MAX_ECDSA_SIG_SIZE);
    if (rc) {
        printf("Error creating ECDSA signature for curve %i, rc=%i.\n", nid, rc);
        return rc;
    }

    rc = ica_ecdsa_verify(adapter_handle, eckey, hash, hash_length,
            signature, MAX_ECDSA_SIG_SIZE);
    switch (rc) {
    case 0:
        printf("Signature verified ok.\n");
        break;
    case EINVAL:
        printf("At least one invalid parameter given.\n");
        break;
    case EFAULT:
        printf("Signature is invalid.\n");
        break;
    default:
        printf("An internal processing error occurred.\n");
        break;
    }

    ica_close_adapter(adapter_handle);

    return rc;
}
```

## ECDH example

```

#include <errno.h>
#include <openssl/crypto.h>
#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include <sys/time.h>

#include <openssl/opensslconf.h>
#ifdef OPENSSL_FIPS
#include <openssl/fips.h>
#endif /* OPENSSL_FIPS */

#include "ica_api.h"
#include "testcase.h"
#include <openssl/obj_mac.h>

#define MAX_ECC_PRIV_SIZE        66 /* 521 bits */
#define MAX_ECDSA_SIG_SIZE        2*MAX_ECC_PRIV_SIZE


int main(int argc, char **argv)
{
    ica_adapter_handle_t adapter_handle;
    unsigned int rc;
    unsigned char shared_secret[MAX_ECC_PRIV_SIZE];
    unsigned int privlen = 0;
    unsigned int nid = NID_X9_62_prime256v1;
    ICA_EC_KEY *eckey1, *eckey2;


    rc = ica_open_adapter(&adapter_handle);
    if (rc != 0) {
        V_(printf("ica_open_adapter failed and returned %d (0x%x).\n", rc, rc));
    }

    /* Create EC key 1 */
    eckey1 = ica_ec_key_new(nid, &privlen);
    if (!eckey1) {
        printf("Unsupported curve.\n");
        return rc;
    }
    rc = ica_ec_key_generate(adapter_handle, eckey1);
    if (rc) {
        printf("EC key for curve %i could not be generated, rc=%i.\n", nid, rc);
        return rc;
    }

    /* Create EC key 2 */
    eckey2 = ica_ec_key_new(nid, &privlen);
    if (!eckey2) {
        printf("Unsupported curve.\n");
        return rc;
    }

    rc = ica_ec_key_generate(adapter_handle, eckey2);
    if (rc) {
        printf("EC key for curve %i could not be generated, rc=%i.\n", nid, rc);
        return rc;
    }

    /* Now derive the shared secret */
    rc = ica_ecdh_derive_secret(adapter_handle, eckey1, eckey2,
                shared_secret, privlen);
    if (rc) {
        printf("Shared secret could not be derived, rc=%i.\n", rc);
        return rc;
    }

    ica_close_adapter(adapter_handle);

    return rc;
}
```

## Makefile example

```
# Specify include directory. Leave blank for default system location.
INCDIR =

# Specify library directory. Leave blank for default system location.
LIBDIR =

# Specify library.
LIBS = -lica

TARGETS = example_aes128_gcm

all: $(TARGETS)

%: %.c
    gcc $(INCDIR) $(LIBDIR) $(LIBS) -o $@ $^

clean:
    rm -f $(TARGETS)
```

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# Glossary

**Advanced Encryption Standard (AES)**
A data encryption technique that improved upon and officially replaced the Data Encryption Standard (DES). AES is sometimes referred to as Rijndael, which is the algorithm on which the standard is based.

**asymmetric cryptography**
Synonym for public key cryptography.

**Block cipher**
An algorithm that encrypts plain text blocks of a fixed length into cipher text blocks. The plain text and cipher text blocks are sequences of bytes. They are always the same size, and that size is fixed by the block cipher. This is called the block cipher's block size.

Examples for block ciphers are DES, Triple-DES, and AES. They are much more secure than stream ciphers.

The block size of AES is always 16 bytes, so input data must be padded up to a multiple of this block length. These padding bytes are removed when decrypting. Thus, the size of encrypted data is normally not equal to the original plain text size.

**CP Assist for Cryptographic Functions (CPACF)**
Hardware that provides support for symmetric ciphers and secure hash algorithms (SHA) on every central processor. Hence the potential encryption/decryption throughput scales with the number of central processors in the system.

**Chinese-Remainder Theorem (CRT)**
A mathematical problem described by Sun Tsu Suan-Ching using the remainder from a division operation.

**Cipher Block Chaining (CBC mode)**
A method of reducing repetitive patterns in cipher-text by performing an exclusive-OR operation on each 8-byte block of data with the previously encrypted 8-byte block before it is encrypted.

**Cipher block length**
The length of a block that can be encrypted or decrypted by a symmetric cipher. Each symmetric cipher has a specific cipher block length.

**clear key**
Any type of encryption key not protected by encryption under another key.

**Counter Mode (CTR mode)**
A block cipher mode where each message block of cipher block size (16 bytes for AES) is combined with a counter value of the same size during encryption and decryption. Starting with an initial counter value to be combined with the first message block, subsequent counter values to be combined with subsequent message blocks are derived from preceding counter values by an increment function. However, the incrementation should generate sequences as much as possible randomly, and guaranteed not to repeat for a long time.

**CPACF instructions**
Instruction set for the CPACF hardware. CPACF functions for DES, TDES and SHA1 functions can be invoked by five new instructions as described in **z/Architecture Principles of Operation**. As a group, these instructions are known as the Message Security Assist (MSA).

**CryptoExpress feature (CEX*S)**
Denotes the IBM cryptographic coprocessor family of PCIe cards, for example, CryptoExpress7S, or CEX7S. The PCIe adapter of a CEX*S feature can be configured in three ways: Either as cryptographic accelerator (CEX*A), or as CCA coprocessor (CEX*C) for secure key encrypted transactions, or in EP11 coprocessor mode (CEX*P) for exploiting Enterprise PKCS #11 functionality.

A CEX*P only supports secure key encrypted transactions.

**ECC**

See *Elliptic curve cryptography*.

**Electronic Code Book (ECB mode)**

A method of enciphering and deciphering data in address spaces or data spaces. Each 64-bit block of plain-text is separately enciphered and each block of the cipher-text is separately deciphered.

**Elliptic curve cryptography (ECC)**

A public-key process discovered independently in 1985 by Victor Miller (IBM) and Neal Koblitz (University of Washington). ECC is based on discrete logarithms. Due to the algebraic structure of elliptic curves over finite fields, ECC provides a similar amount of security to that of RSA algorithms, but with relatively shorter key sizes.

**Federal Information Processing Standards (FIPS)**

A standard published by the US National Institute of Science and Technology.

**FIPS**

see *Federal Information Processing Standards*.

**Galois Counter Mode (GCM mode)**

A block cipher mode. It is usually used together with Advanced Encryption Standard (AES), but could in theory be combined with other block ciphers also, if the block size is 16 bytes.

GCM can do authenticated encryption with associated data. This means, in addition to given plain text, additional data that remains unencrypted can be authenticated, that is, protected against modification. If all data shall remain unencrypted, but authenticated, a so called GMAC (Galois Message Authentication Code) is created. This is simply an authentication mode on the input data.

**libica**

Library for IBM Cryptographic Architecture.

**master key (MK)**

In computer security, the top-level key in a hierarchy of key-encrypting keys.

**MSA**

Message Security Assist. See *CPACF instructions*.

**Mode of operation**

A schema describing how to apply a symmetric cipher to encrypt or decrypt a message that is longer than the cipher block length. The goal of most modes of operation is to keep the security level of the cipher by avoiding the situation where blocks that occur more than once will always be translated to the same value. Some modes of operations allow handling messages of arbitrary lengths. See also: *Block cipher* and *Stream cipher*.

**modulus-exponent (Mod-Expo)**

A type of exponentiation performed using a modulus.

**National Institute of Standards and Technology (NIST)**

A measurement standards laboratory and a non-regulatory agency of the United States Department of Commerce. It is the federal technology agency that works with industry to develop and apply technology, measurements, and standards.

**NIST**

see *National Institute of Standards and Technology*.

**public key cryptography**

In computer security, cryptography in which a public key is used for encryption and a private key is used for decryption. Synonymous with asymmetric cryptography.

**Rivest-Shamir-Adleman (RSA)**

An algorithm used in public key cryptography. These are the surnames of the three researchers responsible for creating this asymmetric or public/private key algorithm.

**Secure Hash Algorithm (SHA)**

A standardized cryptographic hash function to compute a unique (message) digest from a message in a way that is mathematically impossible to reverse. Different data can possibly produce the same hash value, but there is no way to use the hash value to determine the original data.

**secure key**

A key that is encrypted under a master key. When using a secure key, it is passed to a cryptographic coprocessor where the coprocessor decrypts the key and performs the function. The secure key never appears in the clear outside of the cryptographic coprocessor.

**Stream cipher**

Stream ciphers can encrypt any arbitrary number of input bytes, but have significant weaknesses. RC4 is one example of a stream cipher that was heavily used in past decades, but should not be used today. The principle of stream cipher is generating a series of random bytes based on a given key (also called the key stream), and performing an exclusive or (XOR) on the plain text with the key stream bytes.

**symmetric cryptography**

An encryption method that uses the same key for encryption and decryption. Keys of symmetric ciphers are private keys.

**zcrypt device driver**

Kernel device driver to access Crypto Express adapters. Formerly, a monolithic module called **`z90crypt`**. Today, it consists of multiple modules that are implicitly loaded when loading the **ap** main module of the device driver.

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