User Manual

DA16200 DA16600 FreeRTOS SDK Programmer Guide

UM-WI-046

Abstract

The DA16200/DA16600 is a highly integrated ultra-low power Wi-Fi system on a chip (SoC) that allows users to develop a complete Wi-Fi solution on a single chip. This document is an SDK guide which describes the examples that are included in the SDK and is intended for developers who want to develop applications using the DA16200/DA16600 SDK.

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1 Terms and Definitions

AP	Access Point
ADC	Analog-to-Digital Converter
AES	Advanced Encryption Standard
API	Application Programming Interface
AT	Attention
AWS	Amazon Web Services
CCM	Counter with CBC-MAC
CLI	Command Line Interface
CRC	Cyclic Redundancy Check
CTR	Counter
DAC	Digital-To-Analog Converter
DER	Distinguished Encoding Rules
DES	Data Encryption Standard
DHCP	Dynamic Host Configuration Protocol
DMA	Direct Memory Access
DNS	Domain Name Server
DPM	Dynamic Power Management
DRBG	Deterministic Random Bit Generator
DTLS	Datagram Transport Layer Security
DUT	Device Under Test
EAP	Extensible Authentication Protocol
ECDH	Elliptic Curve Diffie-Hellman
ECDSA	Elliptic Curve Digital Signature Algorithm
EVB	Evaluation Board
EVK	Evaluation Kit
GCM	Galois/Counter Mode
GPIO	General-Purpose Input/Output
HMAC	Hash(-based) Message Authentication Code
HTTP	Hypertext Transfer Protocol
HTML	Hypertext Markup Language
I2C	Inter-Integrated Circuit
I2S	Inter-IC Sound
KDF	Key Derivation Function
MQTT	Message Queuing Telemetry Transport
MD5	Message Digest 5
MCU	Microcontroller Unit
NVRAM	Non-volatile Random-Access Memory
OFB	Output Feedback
OTA	Over the Air
PEM	Privacy-Enhanced Mail
POR	Power-On Reset
PWM	Pulse Width Modulation
QoS	Quality of Service
RSA PKCS	RSA Public Key Cryptography Standards
RTC	Real-Time Clock
RTM	Retention Memory

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RTOS	Real-Time Operating System
SD/eMMC	Secure Digital/Embedded Multimedia Card
SDIO	Secure Digital Input Output
SDK	Software Development Kit
SNTP	Simple Network Time Protocol
SPI	Serial Peripheral Interface
SRAM	Static Random-Access Memory
STA	Station
TCP	Transmission Control Protocol
TIM	Traffic Indication Map
TLS	Transport Layer Security
UART	Universal Asynchronous Receiver-Transmitter
UDP	User Datagram Protocol
WPA	Wi-Fi Protected Access
WPA2	Wi-Fi Protected Access 2
WPA3	Wi-Fi Protected Access 3

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2 References

[1] LwIP API. (n.d). Retrieved September 9, 2021. From Savannah: https://www.nongnu.org/lwip/2_0_x/raw_api.html

[2] DA16200, Datasheet, Renesas Electronics

[3] UM-WI-052, DA16600, FreeRTOS Example Application Manual, User Manual, Renesas Electronics

[4] UM-WI-056, DA16200 DA16600, FreeRTOS Getting Started Guide, User Manual, Renesas Electronics

[5] UM-WI-042, DA16200 DA16600, Provisioning Mobile App, User Manual, Renesas Electronics

[6] UM-WI-011, DA16200 DA16600, Mass Production User Manual, User Manual, Renesas Electronics

[7] UM-WI-030, DA16200 DA16600, DPM User Manual, User Manual, Renesas Electronics

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3 Introduction

This document provides an overview of the Software Development Kit (SDK) used for application development based on Wi-Fi solution using the DA16200/DA16600 devices and boards. This SDK includes DA16200/DA16600 generic projects, sample projects, a set of libraries, and drivers to facilitate the creation of various applications by exploiting the provided hardware resources of a connected DA16200/DA16600 devices.

3.1 Overview

The DA16200/DA16600 FreeRTOS SDK has six folders:

- **apps** : project files and source codes for generic and sample applications
  - **apps/common/examples**: sample applications and template
  - **apps/da16xxx/get_started**: generic application
- **core** : source codes for core funnctions
- **docs** : doxgen document and lincens file
- **library** : pre-compiled lib (.a) files
- **tools** : build tools/scripts, temporary build artifacts, or environment files
  - **version** : firmware version files
- **utility** : utilities for programming, debugging, DA14531 SDK, and network tools

The SDK can be used with different features according to use case or applications, and the features can be changed in the SDK.

General features are defined in *~/FreeRTOS_SDK/apps/da16200/<app name>/include/user_main/config_generic_sdk.h* where the features can be enabled or disabled. And other system features are defined in *~/FreeRTOS_SDK/apps/da16200/<app name>/include/user_main/sys_common_features.h.*

NOTE
The main header files including configurable features are located in ./apps/da16xxx/<app name>/include/user_main for generic projects or ./apps/common/examples/<sample group name>/<sample name>/include for sample projects. All features in config_generic_sdk.h are configurable as required. Some features in the sys_common_feature.h can be changed also, but it might need support from Renesas Support Team.

The typical e²studio project for the DA16200/DA16600 SDK is shown in Figure 1.

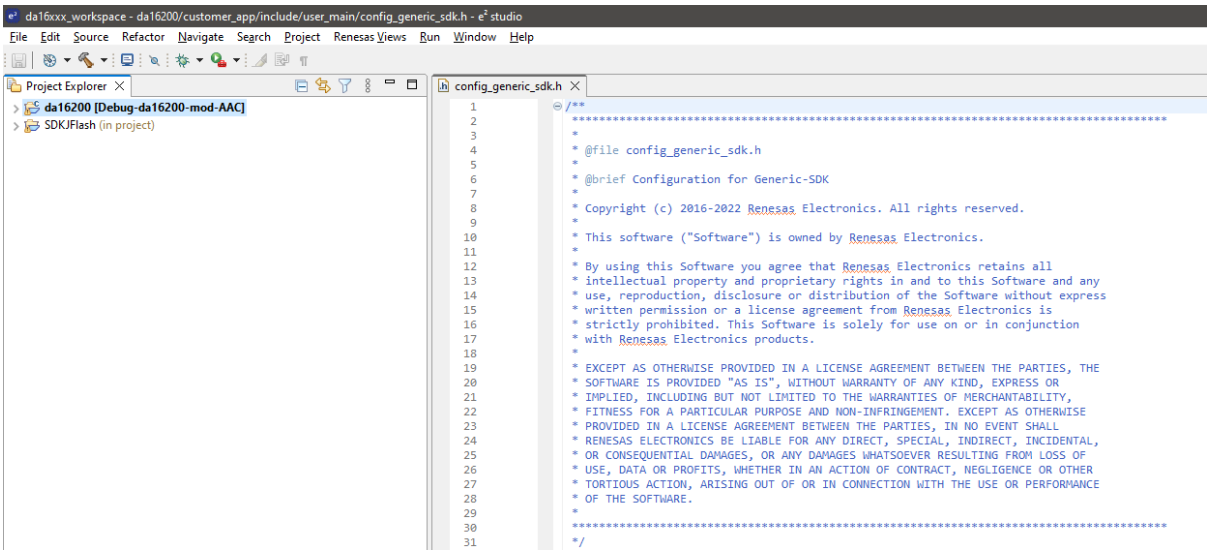

Figure 1: e²studio Project Configuration

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3.2 Development Environment

The DA16200/DA16600 FreeRTOS SDK needs the Renesas e²studio IDE. See the Software Development Kit section of Ref. [4] for e²studio installation.

3.3 System and Application Startup

The `main()` is first startup function. After hardware resources (PIN_MUX, RTC, Console ...) are initialized, `user_main()` in each project is called.

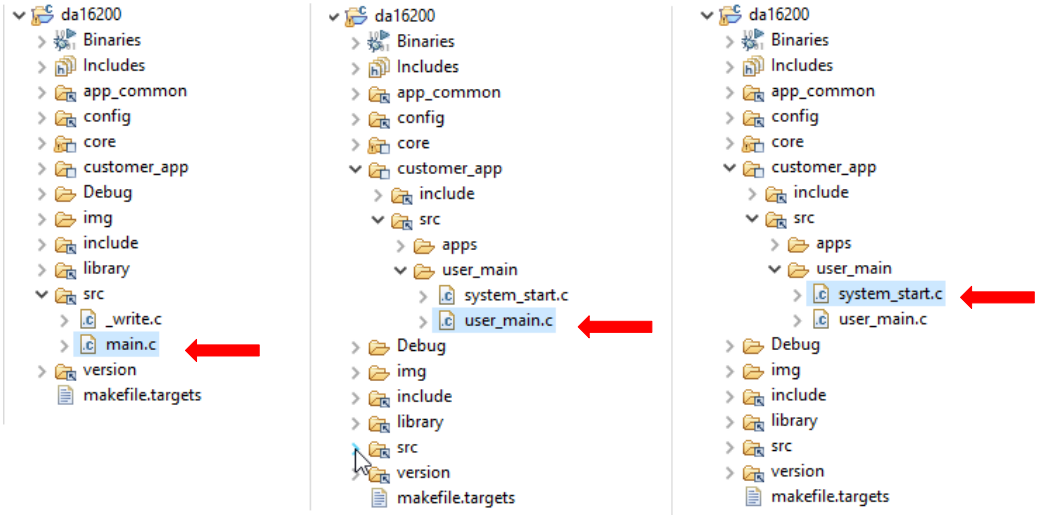

Figure 2: Startup Files on DA16200/DA16600 Project

```
[ ~/FreeRTOS_SDK/core/main/src/main.c ]
  int main(char init_state)
  {
      ...
      xTaskCreate(system_launcher,
                  "system_launcher",
                  256*3,                    // for SecureBoot
                  (void *)NULL,
                  (tskIDLE_PRIORITY+1),
                  NULL);
      ...
      vTaskStartScheduler();
  }

  void system_launcher( void *pvParameters)
  {
      ...
       // Initialize and run system application
       // and run user application if needed.
      start_da16x();
      ...
  }

  static void start_da16x(void)
  {
      ...
      /* Configure Pin-Mux of DA16200 */
      config_pin_mux();
```

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```
    ...
    /* Start DA16200 IoT system layer */
    user_main(ramlib_ptim_init_status); // USER main
}
```

`system_start()` in `user_main()` runs as follows:

- Configure H/W and S/W features
- Configure system resources for system clock and TX power
- Initialize Wi-Fi function in `wlaninit()`
- Start system applications in `start_sys_apps()`
- Start user applications in `start_user_apps()`

```
[~/FreeRTOS_SDK/apps/da16200/<app name>/src/user_main/user_main.c ]
  int user_main(char init_state)
  {
       ...
       /* Entry point for customer main */
       if (init_state == pdTRUE) {
          system_start();
       } else {
          Printf("\nFailed to initialize the RamLib or pTIM !!!\n");
       }

       return status;
  }

[~/FreeRTOS_SDK/apps/da16200/<app name>/src/user_main/system_start.c ]
  int system_start(void)
  {
       /* Config H/W wakeup resource */
       config_user_wu_hw_resource();

       /* Set configuration for H/W button */
       config_gpio_button();

       /* Set paramters for system running */
       set_sys_config();

       /* Initialize WLAN interface */
       wlaninit();

       ... ...

       /* Start system applications for DA16XXX */
       start_sys_apps();

       /*
        * Entry point of user's applications
        *  : defined in user_apps_table.c
        */
       /* Start system applications for DA16XXX */
       start_user_apps();
  }
```

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3.4 System Applications

After the startup function is run, each system application such as MQTT, HTTP server or AT command can be started according to the user defined features.

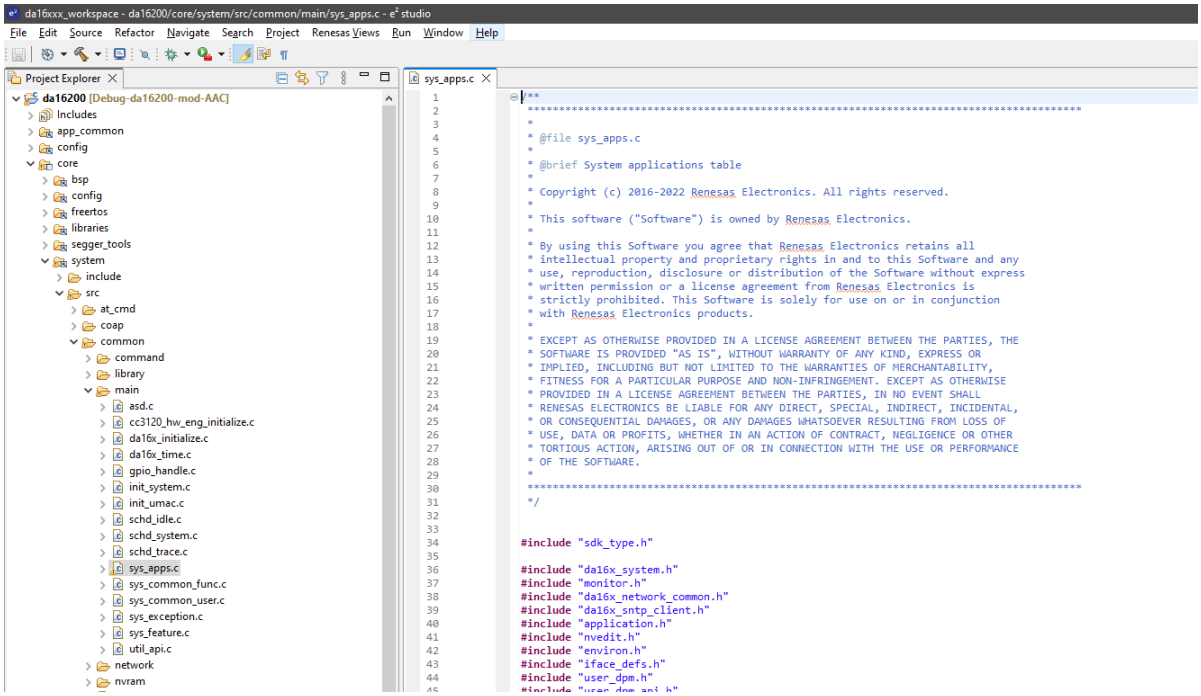

Figure 3: Applications on e²studio Project

```
[ ~/FreeRTOS_SDK/core/system/src/common/main/sys_apps.c ]
  void start_sys_apps(void)
  {
            ...
            /* Start user application functions */
            run_sys_apps();
  }
```

The system applications can run in two cases below:

- Applications run immediately regardless of network connection
- Applications run only after network connection is completed

```
  static void run_sys_apps(void)
  {
       ... ...
       /* Create network independent apps */
       create_sys_apps(sysmode, FALSE);

       /* Create user's network independent apps */
       create_user_apps(sysmode, FALSE);
           ...
       /* wait for network initialization */
       while (1) {
           if (check_net_init(iface) == pdPASS) {
               i = 0;
               break;
           }
```


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```
            i++;
            vTaskDelay(1);
        }
        ...
        /* Check IP address resolution status */
        while (check_net_ip_status(iface)) {
            vTaskDelay(1);
        }

        /* Create network apps */
        create_sys_apps(sysmode, TRUE);
    }
```

All system applications are in the `sys_apps_table[]` as shown in the example code below:

```
[ ~/FreeRTOS_SDK/core/system/src/common/main/sys_apps.c ]
  static const app_task_info_t  sys_apps_table[] =
  {
        /* name, entry_func, stack_size, priority, timeslice, net_chk_flag, dpm_flag,
            port_no, run_sys_mode */

            /****** For function features ***********************************/

            … …

        #if defined ( __SUPPORT_MQTT__ )
        { APP_MQTT_SUB, mqtt_auto_start, 320, (U_PRIO), TRUE, TRUE, UNDEF_PORT,
            RUN_STA_MODE},
        #endif  // __SUPPORT_MQTT__

            … …

        /******* End of List *******************************************/
        { NULL, NULL,   0, 0, FALSE, FALSE, UNDEF_PORT, 0   }

  };
```

The paramters of the `sys_apps_table[]` are as shown below.

```
[ ~/FreeRTOS_SDK/apps/da16200/get_started/include/apps/application.h ]
        typedef struct  _app_task_info {
            /// Thread Name
            char       *name;

            /// Funtion Entry_point
            VOID       (*entry_func)(void *);

            /// Thread Stack Size
            USHORT     stksize;

            /// Thread Priority
            USHORT     priority;

            /// Flag to check network initializing
            UCHAR      net_chk_flag;

            /// Usage flag for DPM running
            UCHAR      dpm_flag;
```

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```
        /// Port number for network communitation
        USHORT    port_no;

        /// Running mode of DA16xxx
        int       run_sys_mode;
    } app_task_info_t;
```

- `name` Unique thread name
- `entry_func` Thread entry point
- `stksize` Stack size of thread
- `priority` Thread running priority
- `net_chk_flag` `TRUE`: run application only after network connection is completed
  `FALSE`: run application immediately regardless of network connection
- `dpm_flag` `TRUE`: register an application to DPM service
  `FALSE`: not register an application to DPM service
- `port_no` Port number of network session for DPM service
- `run_sys_mode` `RUN_STA_MODE`: run application only at Station mode
  `RUN_AP_MODE`: run application only at AP mode
  `RUN_STA_SOFTAP_MODE`: run application only at Concurrent (AP + Station) mode
  `RUN_ALL_MODE`: run application at any mode

NOTE

1. Do not use malloc() or free() function to allocate or free memory. Use pvPortMalloc() or vPortFree() function for allocate or free memory.
2. There is no need to modify the system application tables in the DA16200/DA16600 SDK. However, if required, that can be modified with the support of Renesas Electronics.
3. See Ref. [7] for details about DPM service.

If sample projects in the SDK are used, sample applications also can be run. The sample applications are defined in `sample_apps_table[]` and the parameters are the same as the table of system applications.

```
[ ~/FreeRTOS_SDK/core/system/src/common/main/sys_apps.c ]
static void create_sys_apps(int sysmode, UCHAR net_chk_flag)
{
    … …

    /* Create test samples apps */
    if (sample_app_start_cb != NULL) {
        sample_app_start_cb(net_chk_flag);
    }
}
```

3.5 User Applications

After running the system applications, user applications run in two cases:

- Applications run immediately regardless of network connection

```
        [ ~/FreeRTOS_SDK/core/system/src/common/main/sys_apps.c]
  static void run_sys_apps(void)
```

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```
{
     ... ...

     /* Start user's network independent applications */
     create_user_apps(sysmode, FALSE);
     ... ...
```

- Applications run after network connection is completed

```
     [ ~/FreeRTOS_SDK/core/system/src/common/main/sys_apps.c ]
void start_user_apps(void)
{
     int sysmode;
     … …

     /* Run user's network dependent apps */
     create_user_apps(sysmode, TRUE);
}
```

All user applications are listed in the `user_apps_table[]` as shown in the example code below. There is a "hello_world" application in the SDK and the feature `__SUPPORT_HELLO_WORLD__` is defined in *~/FreeRTOS_SDK/apps/da16200/get_started/include/user_main/config_generic_sdk.h*.

```
[ ~/FreeRTOS_SDK/apps/da16200/get_started/src/apps/user_apps.c ]
const app_task_info_t user_apps_table[] = {
     /* name, func, stack_size, pri, net_flag, dpm_flag, port_no, sys_mode */

     #if defined (__SUPPORT_HELLO_WORLD__)
     { HELLO_WORLD_1, customer_hello_world_1, 64,(U_PRIO),FALSE,FALSE,UNDEF_PORT, ALL_MODE
        },
     { HELLO_WORLD_2, customer_hello_world_2, 64,(U_PRIO),TRUE, FALSE,UNDEF_PORT, ALL_MODE
        },
     #endif  // __SUPPORT_HELLO_WORLD__

     { NULL, NULL,   0, 0, FALSE, FALSE, UNDEF_PORT, 0   }
};
```

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- `HELLO_WORLD_1` This application runs immediately regardless of network connection as shown in Figure 4.
- `HELLO_WORLD_2` This application runs after network connection is completed as shown in Figure 4.

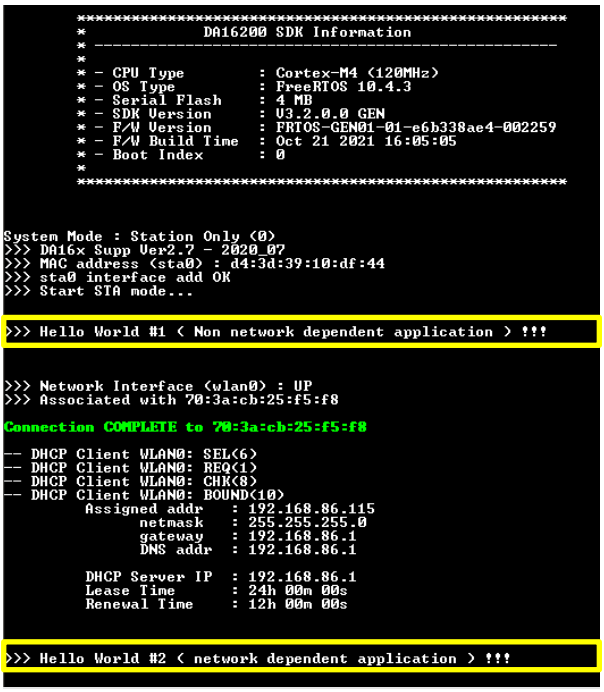

Figure 4: Results of Running Hello World Applications

The applications described above can be reused or new source codes can be added for new applications.

3.6 Sample Applications

The SDK contains various examples which demonstrate how to use DA16200 features. The examples included are:

- **Crypto**: Examples demonstrate how to use the cryptography and security capabilities
- **DPM**: Examples demonstrate how to use the various DPM low power mode
- **ETC**: Examples demonstrate how to get the current time, Access Point scan result
- **Network**: Examples demonstrate how to use various network protocols for either a client or server application
- **Peripheral**: Examples demonstrate how to use the peripherals such as GPIO, I2C, and PWM

Before using the examples, the e^{2}studio development environment must be set up. See Ref. [4] for details on setting up e^{2}studio and importing the DA16200 SDK into that environment.

Once the environment is set up, the examples can be found in the `apps/common/examples` directory. Each example directory has a similar structure and contains its own projects, one for da16200 and one for da16600, which can be imported into the e^{2}studio environment.

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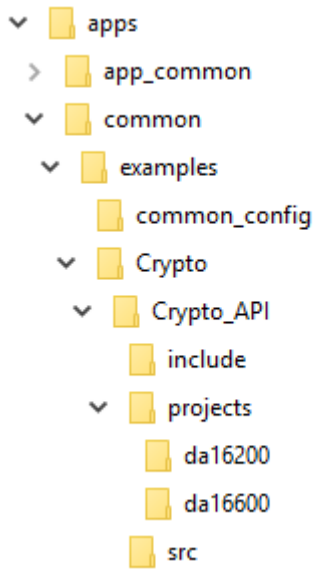

Figure 5: DA16200 SDK Example

Select a desired example project folder and import it to e²studio. See Ref. [4] for how to import projects.

For example, the **Crypto_API** example project is located below:

~/SDK/Apps/common/examples/Crypto/Crypto_API/projects/da16200

3.6.1 Wi-Fi Configuration for Sample Application

Each example using the Wi-Fi communication interface contains default configuration information. This information can be modified in the example code in the following location:

[~/SDK/apps/common/examples/common_config/sample_preconfig.c]

NOTE
Each sample code runs with pre-configured Wi-Fi profile and environment variables in the NVRAM unless users want to add their codes in this file.

```
/* Sample for Customer's Wi-Fi configuration */
#define       SAMPLE_AP_SSID              "TEST_AP_SSID"
#define       SAMPLE_AP_PSK               "12345678"

// CC_VAL_AUTH_OPEN, CC_VAL_AUTH_WEP, CC_VAL_AUTH_WPA, CC_VAL_AUTH_WPA2,
CC_VAL_AUTH_WPA_AUTO
#define SAMPLE_AP_AUTH_TYPE     CC_VAL_AUTH_WPA_AUTO

/* Required when WEP security mode */
#define SAMPLE_AP_WEP_INDEX     0

// CC_VAL_ENC_TKIP, CC_VAL_ENC_CCMP, CC_VAL_ENC_AUTO
#define SAMPLE_AP_ENCRPT_INDEX  CC_VAL_ENC_AUTO

void sample_preconfig(void)
{
    //
    // Need to change as Customer's profile information
    //

#if 0   // Example ...(Customer's code to config Wi-Fi profile for sample code)
```

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```
    char reply[32];

    // Delete existed Wi-Fi profile
    da16x_cli_reply("remove_network 0", NULL, reply);

    // Set new Wi-Fi profile for sample test
    da16x_set_nvcache_int(DA16X_CONF_INT_MODE, 0);
    da16x_set_nvcache_str(DA16X_CONF_STR_SSID_0, SAMPLE_AP_SSID);
    da16x_set_nvcache_int(DA16X_CONF_INT_AUTH_MODE_0, SAMPLE_AP_AUTH_TYPE);

    if (SAMPLE_AP_AUTH_TYPE == CC_VAL_AUTH_WEP)
    {
        da16x_set_nvcache_str(DA16X_CONF_STR_WEP_KEY0 + SAMPLE_AP_WEP_INDEX,
SAMPLE_AP_PSK);
        da16x_set_nvcache_int(DA16X_CONF_INT_WEP_KEY_INDEX, SAMPLE_AP_WEP_INDEX);
    }
    else if (SAMPLE_AP_AUTH_TYPE > CC_VAL_AUTH_WEP)
    {
        da16x_set_nvcache_str(DA16X_CONF_STR_PSK_0, SAMPLE_AP_PSK);
        da16x_set_nvcache_int(DA16X_CONF_INT_ENCRYPTION_0, SAMPLE_AP_ENCRPT_INDEX);
    }

    // Save new Wi-Fi profile to NVRAM area
    da16x_nvcache2flash();

    vTaskDelay(10);

    // Enable new sample Wi-Fi profile
    da16x_cli_reply("select_network 0", NULL, reply);

#endif  // 0
}
```

3.7 Build SDK

After the application is written, right-click on the project **DA16200/DA16600**, and then click **Build Project**. If building a SDK for the first time, it is recommended to run command `Clean` first. See Figure 6.

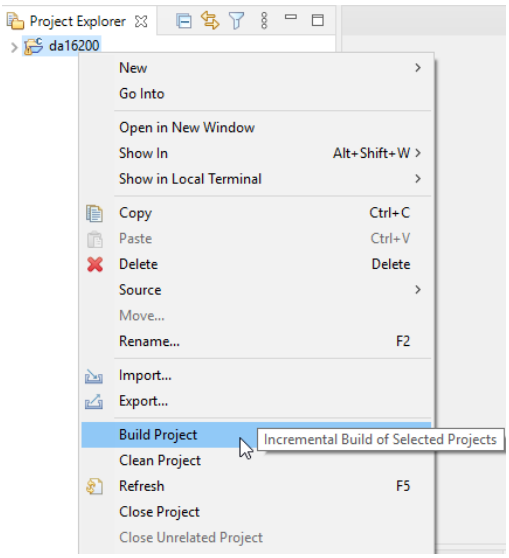

Figure 6: Build SDK on e²studio IDE

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```
CDT Build Console [da16200]
loadscheme : 2
encrscheme : 0
CCRC   : 43b80291
Csize  : 1047248
CPoint : 00101400
Write SFDP (0)
Write [00000050] DBG-CERT-INFO(840)
Write [00000058] DBG-CERT-INFO(840)
Write [00000060] DBG-CERT-INFO(868)
Write [00000068] CERT-Alignment
CertChain : 3
Write [00000070] 1th CERT(848)
Write [000003c0] 2th CERT(848)
Write [00000710] 3th CERT(880)
DbgCertChain : 0
ContentChain : 1
Fill up [0] : 00000980
Write [00000a80]  1th CONTENT(1047248)
------> 2021-10-27 10:43:26.270229
##############################################



 ======> Procedure has been completed successfully ...
da16secutool.py end : 2021-10-27 10:43:26.285850

*----------------------------------------
*Image Generate success
*----------------------------------------

[CM.3.secuboot.bat] END
[.\util\mk_sboot_image.bat] END
*========================================
*Post-Build Clean Start for Windows
*========================================
Start mk_sboot_image_clean.bat
*========================================
*Post-Build End for Windows
*========================================


10:43:27 Build Finished. 0 errors, 92 warnings. (took 1m:51s.912ms)
```

Figure 7: Build Success on e²studio IDE

If the SDK is successfully built, two binary images will be created in the *~/FreeRTOS_SDK/apps/da16200/get_started/img* folder. The names of the image files are:

- RTOS : DA16200_FRTOS-GEN01-01-XXXXXXXXX-000000.img
- 2nd Bootloader : DA16200_FBOOT-GEN01-01-XXXXXXXXX-000000_W25Q32JW.img
  (In case of Winbond W25Q32JW SFLASH)

For more information about the firmware download, see the Programming Firmware Images section of Ref. [4].

3.7.1 Create RTOS Image for fcCSP

By default, the DA16200/DA16600 SDK provides a QFN-type RTOS SFLASH image file. After building the DA16200/DA16600 SDK, the QFN-type RTOS image with filename **DA16200_FRTOS-GEN01-01-XXXXX-000000.img** is created in the **~/SDK/apps/da16200/get_started/img/** folder.

For fcCSP type package, to create a RTOS image with the DA16200/DA16600 SDK, change the build configurations to fcCSP_LP or fcCSP_NP. See Build Configurations section of Ref. [4], and then follow the Build SDK instructions described in Section 3.7. For SDK version 3.2.7.1 or earlier and sample projects, see Appendix F.

When the programming is complete (see Ref. [4] for programming firmware), the SDK version shows "V3.2.x.0 CSP LP" for Low-Power or "V3.2.X.0 CSP NP" for Normal-Power. See Figure 8.

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```
*****************************************************
*              DA16200 SDK Information
* ---------------------------------------------------
*
* - CPU Type          : Cortex-M4 (120MHz)
* - OS Type           : FreeRTOS 10.4.3
* - Serial Flash      : 4 MB
* - SDK Version       : V3.2.2.0 CSP-LP
* - F/W Version       : FRTOS-GEN01-01-58c38acd6-002768
* - F/W Build Time    : Dec 21 2021 15:13:36
* - Boot Index        : 0
*
*****************************************************
```

Figure 8: Boot Logo with fcCSP-LP RTOS Image

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4 NVRAM

The DA16200/DA16600 has an NVRAM area on the flash memory to store system data and user data. NVRAM has various system configuration parameters to control the Wi-Fi function.

4.1 API

There are two types of NVRAM: integer and string. Use the following functions based on the datatype that is currently used.

Table 1: APIs for NVRAM

Item		Description
int write_nvram_int(const char *name, int val)		
Parameter	name	NVRAM item name to write
	value	Integer value to write
Return		If succeeded, return 0. If failed, return an error code.
Description		Write a specific NVRAM item with an integer value
int write_nvram_string(const char *name, const char *val)		
Parameter	name	NVRAM item name to write
	value	Pointer to the string buffer to write
Return		If succeeded, return 0. If failed, return an error code.
Description		Write a specific NVRAM item with a string value
int read_nvram_int(const char *name, int *_val)		
Parameter	name	NVRAM item name to read
	value	Pointer to the integer value to read the value
Return		If succeeded, return 0. If failed return an error code.
Description		Read an integer value of a specific NVRAM item
char *read_nvram_string(const char *name)		
Parameter	name	NVRAM item name to get
	value	Pointer to the string buffer to read the value
Return		If succeeded, return 0. If failed, return an error code.
Description		Read an integer value of a specific NVRAM item

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5 TLS Certificate

Certificate is required to make secure connection, for example, TLS. DA16200 SDK includes MQTT, HTTP client, and WPA Enterprise features which need certificates for secure connection. DA16200 SDK provides APIs to read/write/delete certificates from/to/in sflash memory as shown in Table 2, Table 3, and Table 4.

Table 2: APIs for Reading Certificate from Flash

Item		Description
int da16x_cert_read(int module, int type, int *format, unsigned char *out, size_t *outlen)		
Parameter	module	Module ID. 0 - MQTT, 1 - HTTPs client for OTA, 2 - WPA Enterprise.
	type	Certificate type. 0 - CA certificate, 1 - Certificate, 2 - Private key, 3 - DH params.
	format	Certificate format. 0 - DER, 1 - PEM.
	out	Pointer to read certificate.
	outlen	Length of certificate.
Return		If succeeded, return 0. If failed, return an error code.
Description		Read certificate from specific sflash memory by module and type.
int da16x_cert_read_no_fopen(HANDLE flash_handler, int module, int type, int *format, unsigned char *out, size_t *outlen)		
Parameter	flash_handler	Hanlder to read certificate. It must be open.
	module	Module ID. 0 - MQTT, 1 - HTTPs client for OTA, 2 - WPA Enterprise.
	type	Certificate type. 0 - CA certificate, 1 - Certificate, 2 - Private key, 3 - DH params.
	format	Certificate format. 0 - DER, 1 - PEM.
	out	Pointer to read certificiate.
	outlen	Length of certificate.
Return		If succeeded, return 0. If failed, return an error code.
Description		Read certificate from specific sflash memory by module and type.

Table 3: API to Write Certificate to Flash

Item		Description
int da16x_cert_write(int module, int type, int format, unsigned char *in, size_t inlen)		
Parameter	module	Module ID. 0 - MQTT, 1 - HTTPs client for OTA, 2 - WPA Enterprise.
	type	Certificate type. 0 - CA certificate, 1 - Certificate, 2 - Private key, 3 - DH params.
	format	Certificate format. 0 - DER, 1 - PEM.
	in	Pointer to write certificate.

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Item		Description
int da16x_cert_write(int module, int type, int format, unsigned char *in, size_t inlen)		
	inlen	Length of certificate.
Return		If succeeded, return 0. If failed, return an error code.
Description		Write certificate to specific sflash memory address by module and type.

Table 4: APIs to Delete Certificate in Flash

Item		Description
int da16x_cert_delete(int module, int type)		
Parameter	module	Module ID. 0 - MQTT, 1 - HTTPs client for OTA, 2 - WPA Enterprise.
	type	Certificate type. 0 - CA certificate, 1 - Certificate, 2 - Private key, 3 - DH params.
Return		If succeeded, return 0. If failed, return an error code.
Description		Delete certificate from specific sflash memory by module and type.
int da16x_cert_delete_no_fopen(HANDLE flash_handler, int module, int type)		
Parameter	flash_handler	Hanlder to read certificate. It must be open.
	module	Module ID. 0 - MQTT, 1 - HTTPs client for OTA, 2 - WPA Enterprise.
	type	Certificate type. 0 - CA certificate, 1 - Certificate, 2 - Private key, 3 - DH params.
Return		If succeeded, return 0. If failed, return an error code.
Description		Delete certificate from specific sflash memory by module and type.

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6 H/W Accelerators

6.1 Set SRAM to Zero

6.1.1 API

Table 5: H/W Accelerator API

Item		Description
void da16x_memset32(UINT32 *data, UINT32 seed, UINT32 length)		
Parameter	data	Buffer pointer to set
	seed	Value to fill
	length	Length
Return		None
Description		Fill up memory with a certain value via H/W acceleration

6.1.2 Sample Code

```
#include <hal.h>

/* fill up a 1024 bytes buffer memory with 0 */
UINT32 buffer[1024];
da16x_memset32(buffer, 0, 1024);
```

6.2 CRC Calculation

6.2.1 API

Table 6: CRC API

Item		Description
UINT32 da16x_hwcrc32(UINT32 dwidth, UINT8 *data, UINT32 length, UINT32 seed)		
Parameter	dwidth	Data width to calculate CRC
	data	Data pointer
	length	Length
	seed	CRC32 seed value (default value is 0xFFFFFFFF)
Return		Calculated CRC32 value
Description		Calculate CRC via H/W accelerator

6.2.2 Sample Code

```
#include <hal.h>

/* calculate a CRC value of data buffer */
UINT8 data[64], i;
For (i=0; I < 64; i++)
            data[i] = I;
UINT32 crc_value = da16x_hwcrc32(sizeof(UINT32), (void *)data, sizeof(data),
(~0));
```

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6.3 Pseudo Random Number Generator (PRNG)

6.3.1 API

Table 7: PRNG API

Item		Description
UINT32 da16x_random(void)		
Parameter	None	
Return		32 bits random value
Description		Generate 32 bits random value via H/W accelerator

6.3.2 Sample Code

```
#include <hal.h>

UINT32 random = da16x_random();
```

6.4 Memory Copy Using DMA

6.4.1 API

Table 8: H/W DMA API

Item		Description
int memcpy_dma (void *dest, void *src, unsigned int len, unsigned int wait_time)		
Parameter	dest	A pointer to the location where the function copies the data (4 B Aligned)
	src	A pointer to the buffer where to copy data from (4 B Aligned)
	len	The number of bytes to copy
	wait_time	0: After starting DMA operation, return from function N: Wait until memory copy is finished. If DMA operation time is greater than N milliseconds, the function returns after N milliseconds. N must have a value of at least 10 ms.
Return		Always '0'
Description		Copy bytes from one buffer to another using DMA

6.4.2 Sample Code

```
#include <sys_dma.h>

char dest[100], src[100]

memcpy_dma(dest, src, 100, 0);
```

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7 Watchdog Service

7.1 Overview

The system watchdog service (da16x_sys_watchdog) was designed to monitor system tasks and avoid system freezes. How to interact with the system is shown in Figure 9.

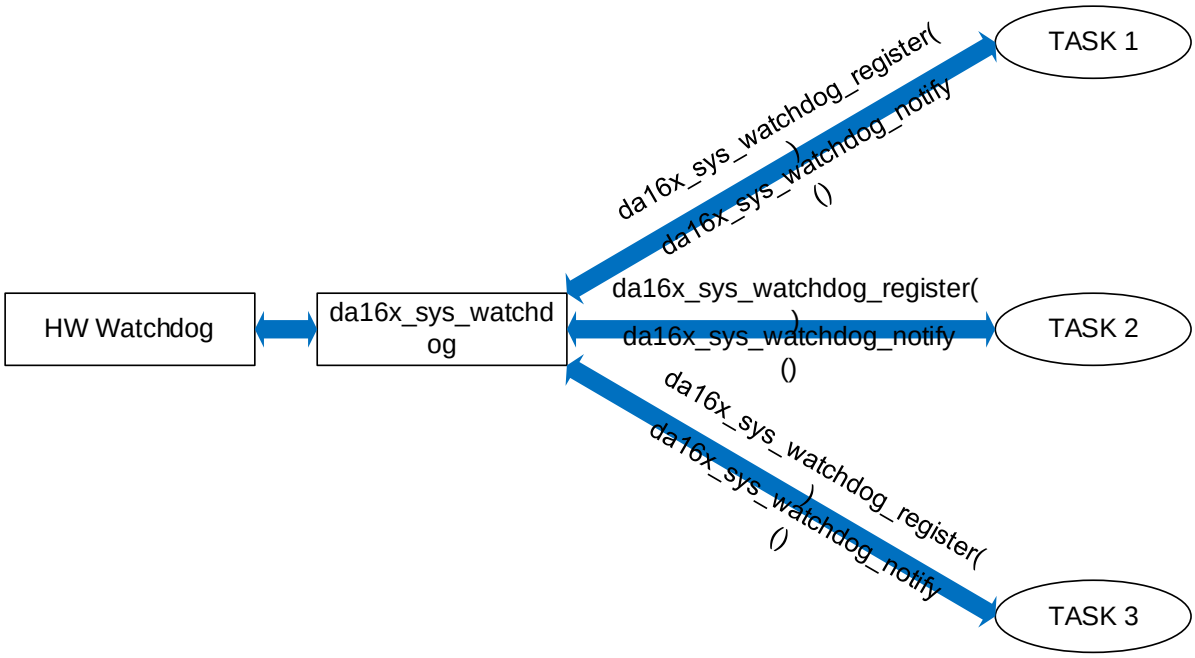

Figure 9: Watchdog Overview

The da16x_sys_watchdog is a layer located on top of the watchdog low-level driver that allows multiple tasks to share the underlying hardware watchdog timer. The watchdog service can be used to trigger a full system reset. This will allow system to recover from a catastrophic failure in one or more tasks.

7.2 Concept

To monitor a task, register the task with da16x_sys_watchdog to receive a unique handle (id). Then, it periodically notifies da16x_sys_watchdog using the id to signal that the task is working properly. When an error occurs during the registeration process, it returns -1.

The DA16200 Watchdog Timer is essentially a simple countdown timer (based on CMSDK Watchdog Timer) that triggers a full system reset if it expires. The watchdog timer interrupt is Non-Maskable interrupt (NMI). That is, the interrupt cannot be disabled and should be controled by Lock/Unlock process. To prevent this, the watchdog timer must be reset to its starting value before it expires. This starting value can be configured via the numberical macro DA16X_SYS_WDOG_DEF_RESCALE_TIME or da16x_sys_watchdog_set_rescale_time() in da16x_sys_watchdog.h file. The default value is 5 seconds.
DA16X_SYS_WDOG_MAX_TASKS_CNT defines the maximum number of tasks that can be monitored.

If all of monitored tasks during one watchdog period notify da16x_sys_watchdog, the hardware watchdog will be updated. In this case, no platform reset will be triggered for this watchdog period. However, a platform reset will be triggered if at least one task does not notify da16x_sys_watchdog in time. There are two ways for a task to notify da16x_sys_watchdog.

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Each task is responsible for periodically notifying da16x_sys_watchdog that it is still running using da16x_sys_watchdog_notify(). This must be done before the watchdog timer expires. Occasionally a registered task may want to temporarily exclude itself from being monitored if it expects to be blocked for a long time waiting for an event. This is done using the da16x_sys_watchdog_suspend(). This function suspends monitoring of specific tasks in da16x_sys_watchdog, as there is no need to monitor a task that is blocked waiting for an event that might task too long to occur (for example, it would lead to the task failed to notify the watchdog service, thus resulting in a system reset). When the task is unblokced, the da16x_sys_watchdog_resume() should be called to restore task monitoring by the watchdog service. From that moment on the task should notify the watchdog service as usual.

Finally, the intension of da16x_sys_watchdog_set_latency() is to be used in cases where a task would require a watchdog period greater than the configured watchdog timer reset value. Using this API allows a task to delay notification of da16x_sys_watchdog for a given number of watchdog periods, without triggering a system reset. The effect of calling the API is one-off, and thus it must be set every time increased latency is required.

7.3 API

Table 9: APIs of Watchdog Service

Item		Description
int da16x_sys_watchdog_init(void)		
Return		If succeeded, return 0. If failed, return an error code.
Description		Initialize da16x_sys_watchdog module.
int da16x_sys_watchdog_register(unsigned int notify_trigger)		
Parameter	notify_trigger	Ture if thask notify should be triggered periodically. It's not supported yet.
Return		Identifier on success, -1 on failure.
Description		Register current task in da16x_sys_watchdog module.
int da16x_sys_watchdog_unregister(int id)		
Parameter	id	Identifier.
Return		If succeeded, return 0. If failed, return an error code.
Description		Unregister task from da16x_sys_watchdog module.
void da16x_sys_watchdog_configure_idle_id(int id)		
Parameter	id	Identifier.
Return		None.
Description		Inform da16x_sys_watchdog module about the wdog id the IDLE task.
int da16x_sys_watchdog_suspend(int id)		
Parameter	id	Identifier.
Return		0 on success.
Description		Suspend task monitoring in da16x_sys_watchdog module.
int da16x_sys_watchdog_resume(int id)		
Parameter	id	Identifier.
Return		0 on success.

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Item		Description
Description		Resume task monitoring in da16x_sys_watchdog module. This function does not notify the watchdog service for this task. It is possible that monitor resuming occurs too close to the time that the watchdog expires, before the task has a chance to explicitly send a notification. This can lead to an unwanted reset. Therefore, either call da16x_sys_watchdog_notify() before calling da16x_sys_watchdog_resume(), or use da16x_sys_watchdog_notify_and_resume() instead.
int da16x_sys_watchdog_notify(int id)		
Parameter	id	Identifier.
Return		0 on success.
Description		Notify da16x_sys_watchdog module for task. Registered task shall use this periodically to notify sys_watchdog module that it's alive. This should be done frequently enough to fit into hw_watchdog interval.
int da16x_sys_watchdog_notify_and_resume(int id)		
Parameter	id	Identifier.
Return		0 on success.
Description		Notify da16x_sys_watchdog module for task with handle \p id and resume its monitoring. This function combines the funtionality of da16x_sys_watchdog_notify() and da16x_sys_watchdog_resume().
int da16x_sys_watchdog_set_latency(int id, unsigned char latency)		
Parameter	id	Identifier.
	latency	Laytency.
Return		0 on success.
Description		Set watchdog latency for task. This allows task to miss given number of notifications to da16x_sys_watchdog without triggering platform reset. Once set, it's allowed that task does not notify sys_watchdog for latency consecutive hw_watchdog intervals which can be used to allow for parts of code which are known to block for long period of time (for example, computation). This value is set once and does not reload automatically, thus it shall be set every time increased latency is required.
int da16x_sys_watchdog_set_rescale_time(unsigned int rescale_time)		
Parameter	rescale_time	Rescale time(unit of times: 10 milliseconds).
Return		0 on success.
Description		Set watchdog rescale time.
int da16x_sys_watchdog_get_rescale_time(unsigned int rescale_time)		
Parameter		None.
Return		Rescale time (unit of times: 10 milliseconds).
Description		Get watchdog rescale time.

7.4 Sample Code

To register the task with da16x_sys_watchdog, use the following code snippet:

```
#include <da16x_sys_watchdog.h>

/* Registration a task to be monitored by watchdog */
wdog_id = sys_watchdog_register(false);
```

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To notify da16x_sys_watchdog, use da16x_watchdog_notify(). If the task is going to suspend for an event, then temporarily exclude the current task from being monitored using da16x_sys_watchdog_suspend(). Once the task has received an event, it can resume its watchdog operation with da16x_sys_watchdog_resume(). This flow is shown below:

```
/* Notify watchdog on each loop since there's no other trigger for this -
 * monitoring will be suspended while blocking on xTaskNotifyWait()
 */
da16x_sys_watchdog_notify(wdog_id);
/*
 * Wait on any of the event group bits, then clear them all
 */
da16x_sys_watchdog_suspend(wdog_id);
ret = xTaskNotifyWait(0, 0xFFFFFFFF, &notif, portMAX_DELAY);
/* Blocks forever waiting for the task notification.
 * Therefore, the return value must always be pdPASS.
 */
da16x_sys_watchdog_resume(wdog_id);
```

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8 Wi-Fi Interface Configuration

The DA16200/DA16600 SDK defines various parameters for Wi-Fi interface configuration, and they are saved as profiles in the NVRAM. After system reset, the DA16200/DA16600 reads an existing profile and sets the Wi-Fi interface based on that profile. Wi-Fi interface can be configured via API, Soft AP configuration, and Soft AP provisioning.

8.1 API

The DA16200/DA16600 SDK provides various functions to get or set system profiles:

- Simple functions to get or set a value (integer type or string type) of the name parameter (NVRAM item index)
- Error code to verify the result

Table 10: APIs for Wi-Fi Configuration

Item		Description
int da16x_set_config_int(int name, int value)		
Parameter	name	Parameter index to set
	value	Integer value to set
Return		If succeeded, return 0 (CC_SUCCESS). If failed, return an error code.
Description		Set a specific parameter with an integer value For example: ret = da16x_set_config_int (Da16x_CONF_INT_CHANNEL, 11) ● Set the operating channel of the AP interface to 11
int da16x_set_config_str (int name, char *value)		
Parameter	name	Parameter index to set
	value	Pointer to the string value to set
Return		If succeeded, return 0 (CC_SUCCESS). If failed, return an error code.
Description		Set a specific parameter with a string value For example: ret = da16x_set_config_int(Da16x_CONF_STR_IP_0, “10.0.0.1”) ● Set the IP address of the STA interface to 10.0.0.1
int da16x_get_config_int (int name, int *value)		
Parameter	name	Parameter index to get
	value	Pointer to the integer variable to get the parameter value
Return		If succeeded, return 0 (CC_SUCCESS). If failed, return an error code.
Description		Get an integer value of a specific parameter For example: ret = da16x_get_config_int(Da16x_CONF_INT_CHANNEL, &channel) ● Get the operating channel of the AP interface
int da16x_get_config_str (int name, char *value)		
Parameter	name	Parameter index to get
	value	Pointer to the string buffer to get the parameter value
Return		If succeeded, return 0 (CC_SUCCESS). If failed, return an error code.
Description		Get a string value of a specific parameter For example: ret = da16x_get_config_str(Da16x_CONF_STR_IP_0, ip_addr) ● Get the IP address of the STA interface

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Item		Description
int da16x_set_nvcache_str(int name, char *value)		
Parameter	name	Parameter name to set
	value	Points to the value (str) to set
Return		If succeeded, return 0 (CC_SUCCESS). If failed, return an error code.
Description		Set name/value pair to NVRAM cache area (not in sflash). To make permanent, invoke da16x_nvcache2flash() For example: ret = da16x_set_nvcache_str(Da16x_CONF_STR_IP_0, ip_addr) ● Set IP address of the STA interface
int da16x_set_nvcache_int(int name, int value)		
Parameter	name	Parameter name to set
	value	Points to the value (int) to set
Return		If succeeded, return 0 (CC_SUCCESS). If failed, return an error code.
Description		Set name/value pair to NVRAM cache area (not in sflash). To make permanent, invoke da16x_nvcache2flash () For example: ret = da16x_set_nvcache_int(Da16x_CONF_INT_CHANNEL, 11) Set the operating channel of the AP interface to 11
void da16x_nvcache2flash(void)		
Parameter	None	
Return		None
Description		Commit parameters (set by da16x_set_nvcache_int/str) in NVRAM cache to flash.

8.1.1 Integer Type Parameters

Table 11: NVRAM Integer Type

Name	Description
DA16X_CONF_INT_MODE	Wi-Fi operation mode 0: STA 1: Soft AP
DA16X_CONF_INT_AUTH_MODE_0	Wi-Fi authentication mode for STA interface CC_VAL_AUTH_OPEN CC_VAL_AUTH_WEP CC_VAL_AUTH_WPA CC_VAL_AUTH_WPA2 CC_VAL_AUTH_WPA_AUTO (WPA & WPA2) CC_VAL_AUTH_WPA_EAP CC_VAL_AUTH_WPA2_EAP CC_VAL_AUTH_WPA_AUTO_EAP
DA16X_CONF_INT_AUTH_MODE_1	Wi-Fi authentication mode for Soft AP interface CC_VAL_AUTH_OPEN CC_VAL_AUTH_WPA CC_VAL_AUTH_WPA2 CC_VAL_AUTH_WPA_AUTO (WPA & WPA2) (WEP is unsupported on the DA16200/DA16600 AP mode)
DA16X_CONF_INT_WEP_KEY_INDEX	Wi-Fi WEP key index number (0~3)

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Name	Description
DA16X_CONF_INT_ENCRYPTION_0	Wi-Fi data encryption mode for STA interface CC_VAL_ENC_TKIP CC_VAL_ENC_CCMP CC_VAL_ENC_AUTO (TKIP & CCMP)
DA16X_CONF_INT_ENCRYPTION_1	Wi-Fi data encryption mode for Soft AP interface CC_VAL_ENC_TKIP CC_VAL_ENC_CCMP CC_VAL_ENC_AUTO (TKIP & CCMP)
DA16X_CONF_INT_WIFI_MODE_0	Wi-Fi mode based on IEEE 802.11 standard for STA interface CC_VAL_WFMODE_BGN CC_VAL_WFMODE_GN CC_VAL_WFMODE_BG CC_VAL_WFMODE_N CC_VAL_WFMODE_G CC_VAL_WFMODE_B
DA16X_CONF_INT_WIFI_MODE_1	Wi-Fi mode based on IEEE 802.11 standard for Soft AP interface CC_VAL_WFMODE_BGN CC_VAL_WFMODE_GN CC_VAL_WFMODE_BG CC_VAL_WFMODE_N CC_VAL_WFMODE_G CC_VAL_WFMODE_B
DA16X_CONF_INT_CHANNEL	Soft AP operation channel setting by channel number 1~11: for US 0: Auto
DA16X_CONF_INT_FREQUENCY	Soft AP operation channel setting by frequency value (MHz)
DA16X_CONF_INT_ROAM	Operating roaming function for STA interface 0: Stop 1: Run
DA16X_CONF_INT_ROAM_THRESHOLD	Roaming threshold for STA interface (-95 ~ 0 dBm)
DA16X_CONF_INT_BEACON_INTERVAL	IEEE 802.11 beacon interval (msec.)
DA16X_CONF_INT_INACTIVITY	Inactive STA disconnecting time (sec.)
DA16X_CONF_INT_RTS_THRESHOLD	IEEE 802.11 RTS threshold (byte)
DA16X_CONF_INT_WMM	WMM On/Off setting 0: Off 1: On
DA16X_CONF_INT_WMM_PS	WMM-PS On/Off setting 0: Off 1: On
DA16X_CONF_INT_DHCP_CLIENT	DHCP client On/Off for STA interface 0: Off 1: On
DA16X_CONF_INT_DHCP_SERVER	DHCP server On/Off for Soft AP interface 0: Off 1: On

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Name	Description
DA16X_CONF_INT_DHCP_LEASE_TIME	DHCP server lease time (sec.)
DA16X_CONF_INT_HIDDEN_0	Flag to connect AP Hidden SSID 0: Off 1: On
DA16X_CONF_INT_EAP_PHASE1_0	Phase#1 EAP type for WPA Enterprise ● CC_VAL_EAP_DEFAULT ● CC_VAL_EAP_PEAP0 ● CC_VAL_EAP_PEAP1 ● CC_VAL_EAP_FAST ● CC_VAL_EAP_TTLS ● CC_VAL_EAP_TLS
DA16X_CONF_INT_EAP_PHASE2_0	Phase#2 EAP type for WPA Enterprise ● CC_VAL_EAP_PHASE2_MIX ● CC_VAL_EAP_MSCHAPV2 ● CC_VAL_EAP_GTC

8.1.2 String Type Parameters

Table 12: NVRAM String Type

Name	Description
DA16X_CONF_STR_SSID_0	AP SSID to connect (~ 32 letters)
DA16X_CONF_STR_SSID_1	Soft AP SSID to operate (~ 32 letters)
DA16X_CONF_STR_WEP_KEY0 DA16X_CONF_STR_WEP_KEY1 DA16X_CONF_STR_WEP_KEY2 DA16X_CONF_STR_WEP_KEY3	WEP keys of the AP to connect (5 or 13 letters with ASCII / 10 or 26 letters with hexadecimal)
DA16X_CONF_STR_PSK_0	PSK of the AP to connect (~ 63 letters)
DA16X_CONF_STR_PSK_1	Soft AP PSK to operate (~ 63 letters)
DA16X_CONF_STR_COUNTRY	Country code (2 or 3 letters, for example, KR, US, JP, CH) defined by ISO 3166-1 alpha-2 standard
DA16X_CONF_STR_DEVICE_NAME	DA16200/DA16600 device name (for WPS or Wi-Fi Direct)
DA16X_CONF_STR_IP_0	STA interface IP address
DA16X_CONF_STR_NETMASK_0	STA interface netmask
DA16X_CONF_STR_GATEWAY_0	STA interface gateway address
DA16X_CONF_STR_IP_1	Soft AP interface IP address
DA16X_CONF_STR_NETMASK_1	Soft AP interface netmask
DA16X_CONF_STR_GATEWAY_1	Soft AP interface gateway address
DA16X_CONF_STR_DNS_0	STA interface DNS address
DA16X_CONF_STR_DHCP_START_IP DA16X_CONF_STR_DHCP_END_IP	DHCP server IP range assigned
DA16X_CONF_STR_DHCP_DNS	DHCP server DNS IP address assigned
DA16X_CONF_STR_EAP_IDENTITY	User-ID for WPA Enterprise (~ 64 letters)
DA16X_CONF_STR_EAP_PASSWORD	Password for WPA Enterprise (~ 64 letters)

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8.1.3 Sample Code

When setting multiple names at the same time, use da16x_set_nvcache_int/str() and da16x_nvcache2flash(). Using da16x_set_config_str/int() is good for setting one or two values, but if it needs to set multiple NVRAM parameters (that is, Soft AP/STA setup), then always use cache function da16x_set_nvcache_int/str followed by da16x_nvcache2flash(), which will give much better performance to the application.

The following example explains how to set STA mode.

```
/* Wi-Fi Configuration */

clear_tmp_nvram_env();  // Clear Cache


// start setting names/values of NVRAM parameters to NVRAM Cache (no delay)

da16x_set_nvcache_int(DA16X_CONF_INT_MODE, 0);
da16x_set_nvcache_str(DA16X_CONF_STR_SSID_0, ssid);
da16x_set_nvcache_int(DA16X_CONF_INT_AUTH_MODE_0, auth_type);
if (auth_type == CC_VAL_AUTH_WEP) {
              da16x_set_nvcache_str(DA16X_CONF_STR_WEP_KEY0, wep_key[0]);
              da16x_set_nvcache_str(DA16X_CONF_STR_WEP_KEY1, wep_key[1]);
              da16x_set_nvcache_str(DA16X_CONF_STR_WEP_KEY2, wep_key[2]);
              da16x_set_nvcache_str(DA16X_CONF_STR_WEP_KEY3, wep_key[3]);
              da16x_set_nvcache_str(DA16X_CONF_INT_WEP_KEY_INDEX, wep_key_index);
} else if (auth_type > CC_VAL_AUTH_WEP) {
       da16x_set_nvcache_str(DA16X_CONF_STR_PSK_0, psk);
       da16x_set_nvcache_int(DA16X_CONF_INT_ENCRYPTION_0, encryption);
}
da16x_set_nvcache_int(DA16X_CONF_INT_WIFI_MODE_0, wifi_mode);

/* IP & DHCP Client Setting */
da16x_set_nvcache_int(DA16X_CONF_INT_DHCP_CLIENT, dhcp_client);
if (!dhcp_client) {
       da16x_set_nvcache_str(DA16X_CONF_STR_IP_0, ip);
       da16x_set_nvcache_str(DA16X_CONF_STR_NETMASK_0, subnet);
       da16x_set_nvcache_str(DA16X_CONF_STR_GATEWAY_0, gateway);
       da16x_set_nvcache_str(DA16X_CONF_STR_DNS_0, dns);
}

da16x_nvcache2flash();  // commit names/values parameters in Cache to flash memory


reboot_func(SYS_REBOOT);
```

The following example explains how to set STA mode for WPA Enterprise. Depending on the wireless environment, the certificate may be required when connecting to WPA Enterprise network. In this case, the Certificate API might be helpful to write to sflash memory.

```
/* Certificate */
da16x_cert_write(DA16X_CERT_MODULE_WPA_ENTERPRISE, DA16X_CERT_TYPE_CA_CERT, ca_cert,
ca_cert_len); // Write CA Certificate
da16x_cert_write(DA16X_CERT_MODULE_WPA_ENTERPRISE, DA16X_CERT_TYPE_CERT, cert,
cert_len); // Write Certificate
da16x_cert_write(DA16X_CERT_MODULE_WPA_ENTERPRISE, DA16X_CERT_TYPE_PRIVATE_KEY,
priv_key, priv_key_len); // Write Private key
da16x_cert_write(DA16X_CERT_MODULE_WPA_ENTERPRISE, DA16X_CERT_TYPE_DH_PARAMS,
dh_param, dh_param_len); // Write Private key

/* Wi-Fi Configuration */
clear_tmp_nvram_env(); // Clear Cache
```

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```
// start setting names/values of NVRAM parameters to NVRAM Cache (no delay)
da16x_set_nvcache_str(DA16X_CONF_STR_SSID_0, ssid);          //Set SSID
da16x_set_nvcache_int(DA16X_CONF_INT_AUTH_MODE_0, auth_mode);// Set Auth mode
da16x_set_nvcache_int(DA16X_CONF_INT_ENCRYPTION_0, enc_type);// Set Encryption type
da16x_set_nvcache_int(DA16X_CONF_INT_EAP_PHASE1, eap_phase1);// Set EAP Phase#1
type
da16x_set_nvcache_int(DA16X_CONF_INT_EAP_PHASE2, eap_phase2);// Set EAP Phase#2
type
da16x_set_nvcache_str(DA16X_CONF_STR_EAP_IDENTITY, user_id); // Set User-ID
da16x_set_nvcache_str(DA16X_CONF_STR_EAP_PASSWORD, password);// Set Password

da16x_nvcache2flash(); // commit names/values parameters in Cache to flash memory

reboot_func(SYS_REBOOT);
```

The following example explains how to set Soft AP mode.

```
/* Soft AP Configuration */
```

clear_tmp_nvram_env(); // Clear Cache

```
...
// start setting name/value NVRAM parameters to NVRAM Cache (no delay)
da16x_set_nvcache_int(DA16X_CONF_INT_MODE, 1);
da16x_set_nvcache_str(DA16X_CONF_STR_SSID_1, ssid);
da16x_set_nvcache_int(DA16X_CONF_INT_AUTH_MODE_1, auth_type);
if (auth_type > CC_VAL_AUTH_WEP) {
       da16x_set_nvcache_str (DA16X_CONF_STR_PSK_1, psk);
       da16x_set_nvcache_int(DA16X_CONF_INT_ENCRYPTION_1, encryption);
}
da16x_set_nvcache_int(DA16X_CONF_INT_CHANNEL, channel);
da16x_set_nvcache_int(DA16X_CONF_STR_COUNTRY, country_code);
da16x_set_nvcache_int(DA16X_CONF_INT_WIFI_MODE_1, wifi_mode);
da16x_set_nvcache_int(DA16X_CONF_INT_WMM, wmm);
da16x_set_nvcache_int(DA16X_CONF_INT_WMM_PS, wmm_ps);

/* IP Setting */
da16x_set_nvcache_str(DA16X_CONF_STR_IP_1, ip);
da16x_set_nvcache_str(DA16X_CONF_STR_NETMASK_1, subnet);
da16x_set_nvcache_str(DA16X_CONF_STR_GATEWAY_1, gateway);

/* DHCP Server Setting */
if (dhcp_server) {
       da16x_set_nvcache_str(DA16X_CONF_STR_DHCP_START_IP, start_ip);
       da16x_set_nvcache_str(DA16X_CONF_STR_DHCP_END_IP, end_ip);
      da16x_set_nvcache_str(DA16X_CONF_STR_DHCP_DNS, dhcp_dns);
       da16x_set_nvcache_str(DA16X_CONF_INT_DHCP_LEASE_TIME, dhcp_lease_time);
}
da16x_set_nvcache_int(DA16X_CONF_INT_DHCP_SERVER, dhcp_server);
```

da16x_nvcache2flash(); // commit names/values parameters in Cache to flash memory

```
reboot_func(SYS_REBOOT);
```

8.2 Soft AP Configuration by Factory Reset

Many IoT devices start as a Soft AP device to operate AP provisioning. The DA16200/DA16600 has a Factory Reset function to start with Soft AP mode after pressing the Factory Reset button on the evaluation board. The details of Factory Reset button can be found in DA16200 and DA16600 EVKs

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(look for S2- Factory Reset Button) in Ref. [4], and it is connected to GPIO 7 on the DA16200/DA16600 EVB.

The DA16200/DA16600 SDK offers a simple method for users to configure the Soft AP interface with their own values. This section describes how to configure the default values in the DA16200/DA16600 SDK.

8.2.1 Configure Data Structure

The DA16200/DA16600 SDK has the structure to configure Soft AP interface. The details can be found in the example below.

[~/FreeRTOS_SDK/core/system/include/common/da16x_network_common.h]

```
/* For Customer's Soft AP configuration */
#define       MAX_SSID_LEN        32
#define       MAX_PASSKEY_LEN     64
#define       MAX_IP_ADDR_LEN     16

#define       AP_OPEN_MODE        0
#define       AP_SECURITY_MODE    1

#define       IPADDR_DEFAULT      0
#define       IPADDR_CUSTOMER     1

#define       DHCPD_DEFAULT       0
#define       DHCPD_CUSTOMER      1

typedef struct _Soft AP_config {
      int     customer_cfg_flag;  // MODE_ENABLE, MODE_DISABLE


      char    ssid_name[MAX_SSID_LEN+1];
      char    psk[MAX_PASSKEY_LEN+1];
      char    auth_type;          // AP_OPEN_MODE, AP_SECURITY_MODE
      char    country_code[4];

      int     customer_ip_address;// IPADDR_DEFAULT, IPADDR_CUSTOMER
      char    ip_addr[MAX_IP_ADDR_LEN];
      char    subnet_mask[MAX_IP_ADDR_LEN];
      char    default_gw[MAX_IP_ADDR_LEN];
      char    dns_ip_addr[MAX_IP_ADDR_LEN];

      int     customer_dhcpd_flag;// DHCPD_DEFAULT, DHCPD_CUSTOMER
      //int   dhcpd_ip_cnt;
      int     dhcpd_lease_time;
      char    dhcpd_start_ip[MAX_IP_ADDR_LEN];
      char    dhcpd_end_ip[MAX_IP_ADDR_LEN];
      char    dhcpd_dns_ip_addr[MAX_IP_ADDR_LEN];
} Soft AP_config_t;
```

- int customer_cfg_flag: Flag for Soft AP configuration
  - MODE_DISABLE (0) : Do not use Soft AP configuration
  - MODE_ENABLE (1) : Use Soft AP configuration
- char ssid_name[MAX_SSID_LEN+1]: SSID of Soft AP. Max length is 32 bytes.
- char psk[MAX_PASSKEY_LEN]: Pairwise key. Max length is 64 bytes.
- char auth_type: Authentication type
  - OPEN_MODE (0)

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- AP_SECURITY_MODE (1)

- char country_code [4]: Country code
  See the Appendix D.
- int customer_ip_address: IP address type
  - IPADDR_DEFAULT (0) : IP class is 10.0.0.1
  - IPADDR_CUSTOMER (1) : User defined IP address
    The following parameters should be defined:

```
char   ip_addr[MAX_IP_ADDR_LEN]
char   subnet_mask[MAX_IP_ADDR_LEN]
char   default_gw[MAX_IP_ADDR_LEN]
char   dns_ip_addr[MAX_IP_ADDR_LEN]
```

- int customer_dhcpd_flag: DHCP server IP address range
  - DHCPD_DEFAULT (0) : 10.0.0.2 ~ 10.0.0.11 (10 clients)
  - DHCPD_CUSTOMER (1) : User defined range
    Need to define the following parameters:

```
int    dhcpd_lease_time
char   dhcpd_start_ip[MAX_IP_ADDR_LEN]
char   dhcpd_end_ip[MAX_IP_ADDR_LEN]
char   dhcpd_dns_ip_addr[MAX_IP_ADDR_LEN]
```

8.2.2 Configure Soft AP Interface

The DA16200/DA16600 SDK has the function to configure the Soft AP interface. This function is invoked when a factory reset is done. Users can write their own values, and the details can be found in the example below.

[~/FreeRTOS_SDK/customer/user_main/src/system_start.c]

```
void set_customer_Soft AP_config(void)
{
#ifdef __SUPPORT_FACTORY_RST_APMODE__
      /* Set to user costomer's configuration */
      ap_config_param->customer_cfg_flag = MODE_DISABLE;
        // MODE_ENABLE, MODE_DISABLE
      /*
       * Wi-Fi configuration
       */
        /* SSID prefix */
      sprintf(ap_config_param->ssid_name, "%s", "DA16200");

      /* Default open mode: AP_OPEN_MODE, AP_SECURITY_MODE */
      ap_config_param->auth_type = AP_OPEN_MODE;
      if (ap_config_param->auth_type == AP_SECURITY_MODE);
        sprintf(ap_config_param->psk, "%s", "12345678");

      /* Country Code: Default country US */
      sprintf(ap_config_param->country_code, "%s", DFLT_AP_COUNTRY_CODE);

      /*
       * Network IP address configuration
       */
      ap_config_param->customer_ip_address = IPADDR_DEFAULT;
      if (ap_config_param->customer_ip_address == IPADDR_CUSTOMER) {
        sprintf(ap_config_param->ip_addr, "%s", "192.168.1.1");
        sprintf(ap_config_param->subnet_mask,    "%s", "255.255.255.0");
        sprintf(ap_config_param->default_gw,     "%s", "192.168.1.1");
        sprintf(ap_config_param->dns_ip_addr,    "%s", "8.8.8.8");
```


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```
        }

        /*
         * DHCP Server configuration
         */
        ap_config_param->customer_dhcpd_flag = DHCPD_DEFAULT;
        if (ap_config_param->customer_dhcpd_flag == DHCPD_CUSTOMER) {
         ap_config_param->dhcpd_lease_time = 3600;

         sprintf(ap_config_param->dhcpd_start_ip, "%s", "192.168.1.101");
         sprintf(ap_config_param->dhcpd_end_ip, "%s", "192.168.1.108");
         sprintf(ap_config_param->dhcpd_dns_ip_addr, "%s", "8.8.8.8");
        }
#endif /* __SUPPORT_FACTORY_RST_APMODE__ */
}
```

8.3 Soft AP Provisioning Protocol

The DA16200/DA16600 supports the Soft AP mode for a Wi-Fi interface setup. The provisioning thread automatically runs when the DA16200/DA16600 starts in the Soft AP mode. See Ref. [5] for details.

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9 Network Examples: Socket Communication

This section describes how to develop Transmission Control Protocol (TCP) or User Datagram Protocol (UDP) socket applications using the lwIP (Lightweight IP) APIs in the DA16200/DA1600 SDK. As a companion document, see Ref. [1] for more details on all functions. To understand and implement applications using the DPM API, both non-DPM and DPM examples are provided. Before testing these examples, a test environment as shown in Figure 10 is required.

9.1 Test Environment

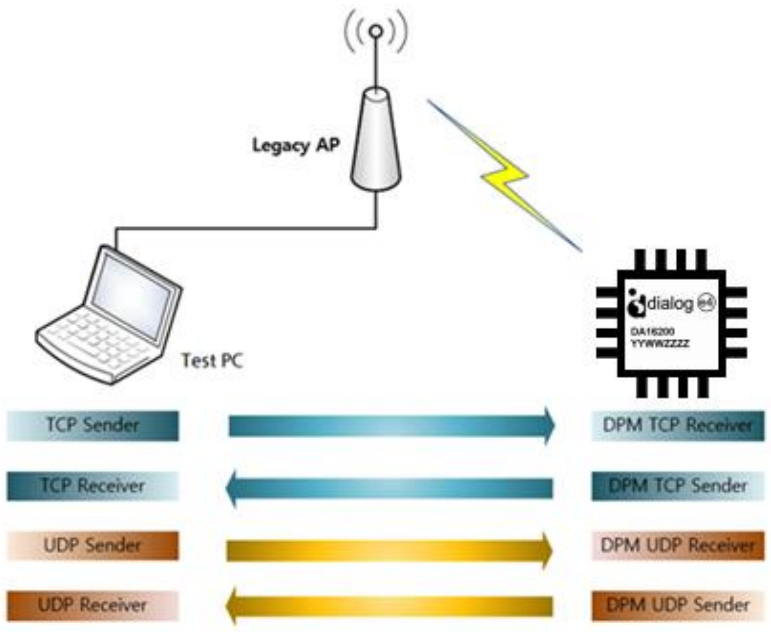

Figure 10: Overall Test Setup

9.1.1 DA16200

The files of example sources are included in the DA16200 SDK. The examples in this section require the DA16200 to be configured as a Wi-Fi station (STA Mode). See the Setup for Station Mode section of Ref. [4] on how to set up Wi-Fi station mode. Also, after completed the STA mode setup, copy the IP address of the DA16200 EVB for later use. The IP address is printed after connecting to an Access Point (AP), and then TCP/UDP example application will be executed. See Figure 11.

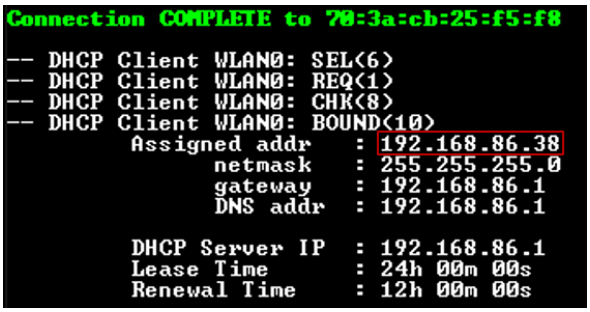

Figure 11: DA16200 EVB – AP Connection Complete

9.1.2 Peer Application

The examples in this section require a peer device (PC/Laptop) connected to the same AP running a TCP/UDP test application such as IO Ninja.

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NOTE
For the Windows OS system, the user needs to install a proper application such as Packet Sender, Hercules, and IO Ninja. For a Linux system, proper test utilities or a test sample application is needed.

9.1.2.1 Example of Peer Application

This section describes how to run the peer application on the Windows operating system.

1. Start the IO Ninja utility on the test PC.
   If it is not installed, download it from http://ioninja.com.
2. Select **File** > **New Session** for the test.

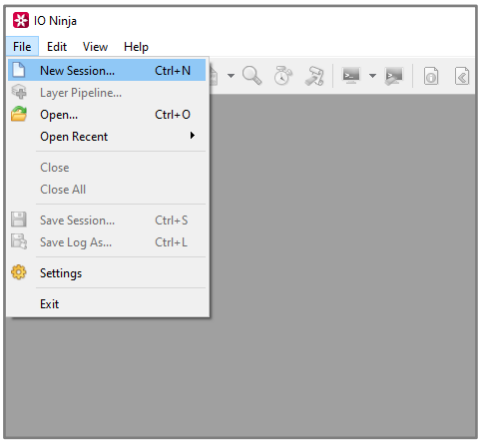

Figure 12: Start IO Ninja Utility

3. To test the TCP Client, start the TCP Server.

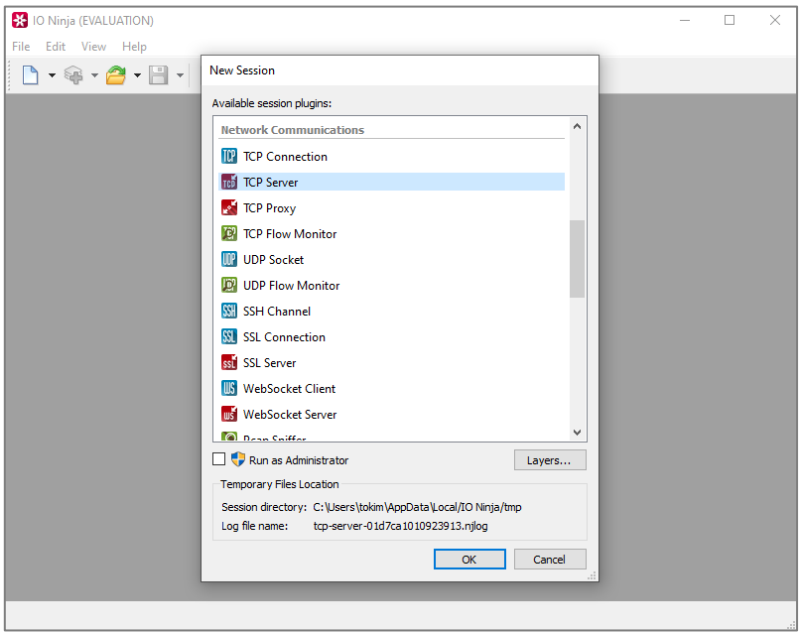

Figure 13: Select TCP Server Session

4. If **TCP Listener Socket** is selected, IO Ninja utility shows the TCP server test window.

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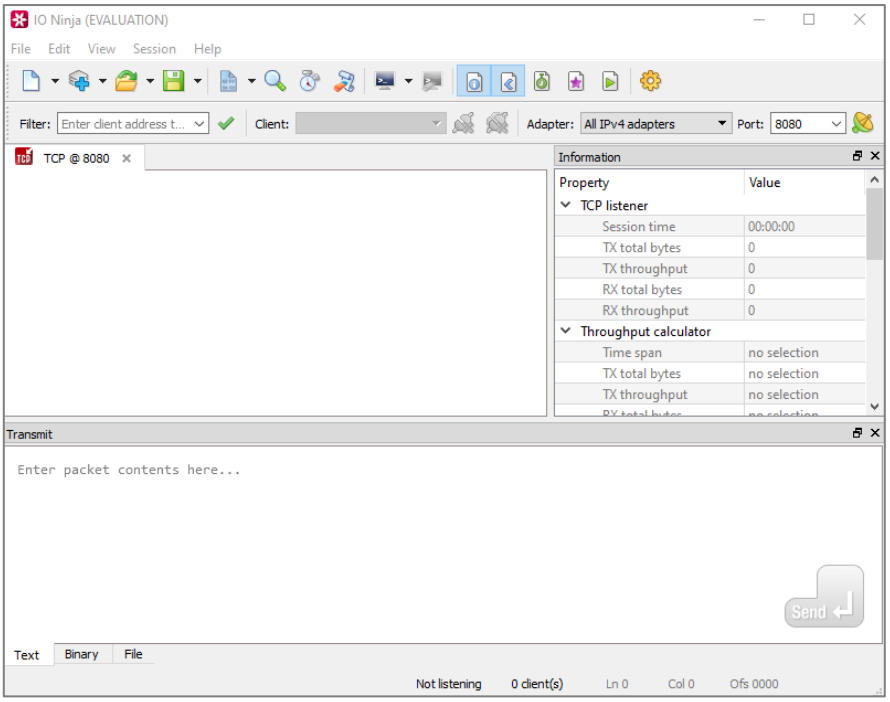

Figure 14: TCP Server Session Windows

5. Start the TCP Server session (for example, TCP Client test).

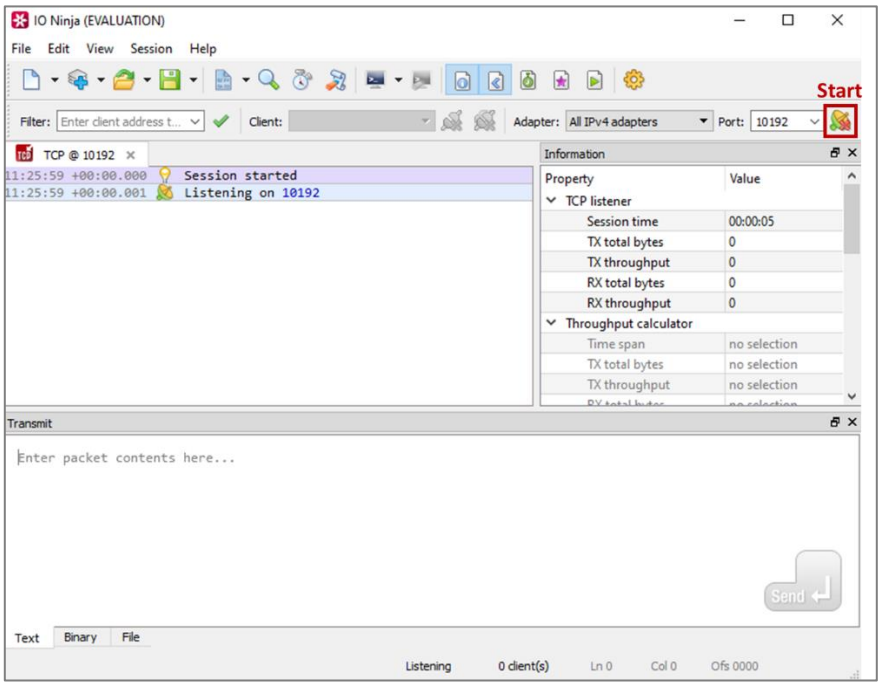

Figure 15: Start TCP Server Session

6. Connect to the TCP Client.

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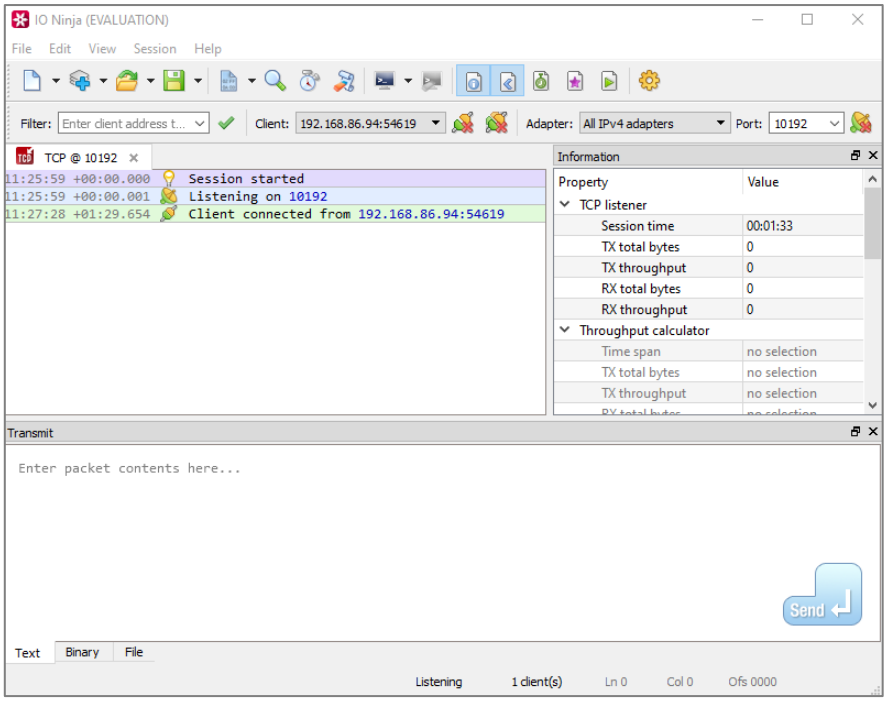

Figure 16: TCP Connection with TCP Client

7. Run data communication.

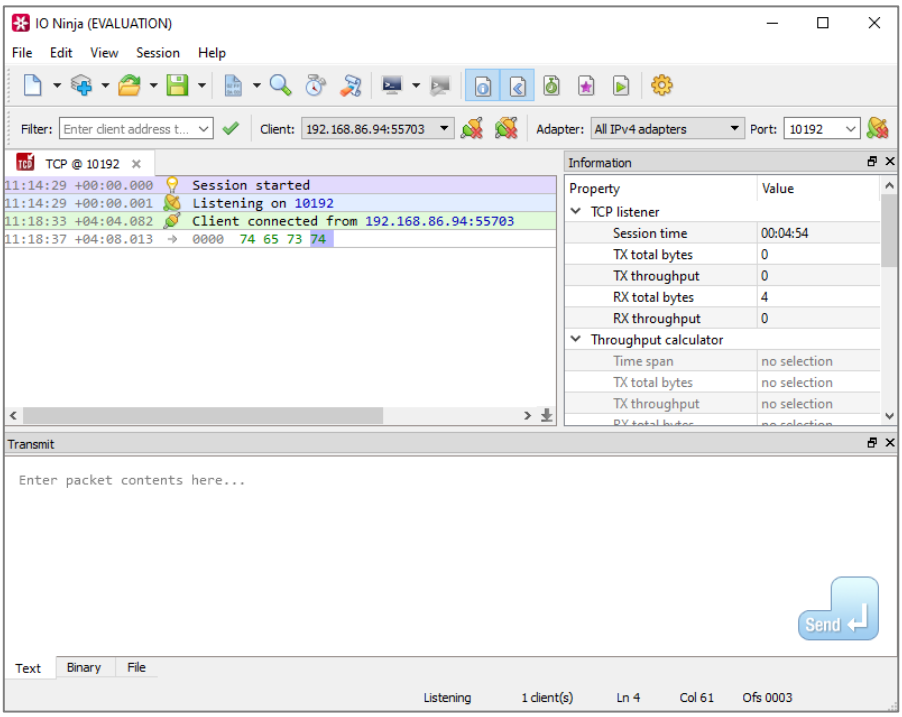

Figure 17: TCP Data Communication with TCP Client

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9.2 TCP Client

This section describes how the TCP client sample application is built and operated. The TCP client sample is an example of the simplest TCP echo client application. TCP is one of the main protocols of the Internet protocol suite. TCP provides a reliable, ordered, and error-checked delivery of a stream of octets (bytes) between applications that run on hosts that communicate via an IP network. The DA16200 SDK provides a lwIP's TCP protocol. lwIP is an open-source TCP/IP stack designed for embedded system.

9.2.1 How to Run

1. Run a socket application on the peer PC (see Section 9.1.2) and open a TCP server socket with port number 10192 (default TCP Client test port).
2. In the e²studio, import a project for TCP Client sample application as follows:
   `~/SDK/apps/common/examples/Network/TCP_Client/projects/da16200`
3. Build the DA16200 SDK, download the RTOS image to the DA16200 EVB, and reboot.
4. Use the console command to set up the Wi-Fi station interface.
5. To set the IP address and port for the peer application (TCP Server) in the TCP Client Sample, edit the source code:
   `~/SDK/apps/common/examples/Network/TCP_Client/src/tcp_client_sample.c`

```
#define TCP_CLIENT_SAMPLE_DEF_SERVER_IP_ADDR            "192.168.0.11"
#define TCP_CLIENT_SAMPLE_DEF_SERVER_PORT                    TCP_CLI_TEST_PORT
```

The example connects to the peer application (TCP Server) after a connection is made to the Wi-Fi AP.

9.2.2 How It Works

The DA16200 TCP Client sample application is a simple echo message. When the TCP server sends a message, the DA16200 TCP client echoes that message to the TCP server.

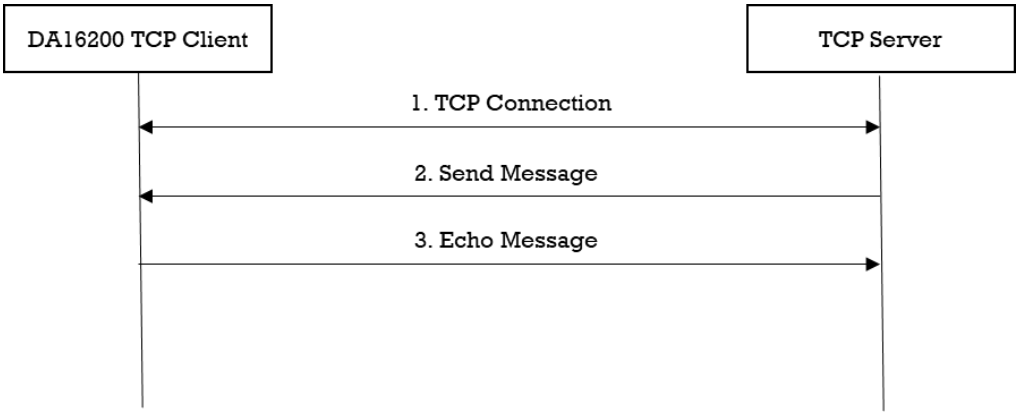

Figure 18: Workflow of TCP Client

9.2.3 Sample Code

The DA16200 SDK provides the lwIP's TCP protocol. This sample application describes how a TCP socket is created, deleted, and configured.

9.2.3.1 Registration

The client side of the TCP connection initiates a connection request to a TCP server. The client TCP socket should be created with the socket () service and bound to a port via the bind() service. After the client socket is bound, the connect() service is used to establish a connection with a TCP server.

```
void tcp_client_sample(void *param)
```


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```
{
      int ret = 0;
      int socket_fd;
      struct sockaddr_in local_addr;
      struct sockaddr_in srv_addr;

      memset(&local_addr, 0x00, sizeof(struct sockaddr_in));
      memset(&srv_addr, 0x00, sizeof(struct sockaddr_in));
      // Create TCP socket
      socket_fd = socket(PF_INET, SOCK_STREAM, 0);

      local_addr.sin_family = AF_INET;
      local_addr.sin_addr.s_addr = htonl(INADDR_ANY);
      local_addr.sin_port = htons(TCP_CLIENT_SAMPLE_DEF_PORT);

      // Bind TCP socket
      ret = bind(socket_fd, (struct sockaddr *)&local_addr,
                 sizeof(struct sockaddr_in));

      srv_addr.sin_family = AF_INET;
      srv_addr.sin_addr.s_addr = inet_addr(TCP_CLIENT_SAMPLE_DEF_SERVER_IP_ADDR);
      srv_addr.sin_port = htons(TCP_CLIENT_SAMPLE_DEF_SERVER_PORT);

      // Connect TCP socket
      ret = connect(socket_fd, (struct sockaddr_in *)&srv_addr,
                    sizeof(struct sockaddr_in));
          ....
}
```

9.2.3.2 Data Transmission

TCP data is received when function recv() is called. TCP incoming packet handles various connections and disconnections and is responsible for acknowledging transmissions.

TCP data is sent when function send() is called. This service first builds a TCP header in the front part of the packet (including the checksum calculation). If the receiver's window size is larger than the data in this packet, the packet is sent to the internet with the internal IP send routine. Otherwise, the caller may be suspended and wait for the receiver's window size to increase enough for this packet to be sent. At any given time, only one sender may suspend while trying to send TCP data.

```
void tcp_client_sample()
{
    ...
    while (1) {
        memset(data_buffer, 0x00, sizeof(data_buffer));

        PRINTF("< Read from server: ");
        len = recv(socket_fd, data_buffer, sizeof(data_buffer), 0);
        data_buffer[len] = '\0';
        PRINTF("%d bytes read\r\n", len);

        PRINTF("> Write to server: ");
        len = send(socket_fd, data_buffer, len, 0);
        PRINTF("%d bytes written\r\n", len
    }
    ...
}
```

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9.2.3.3 Disconnection

The connection is closed when function close() is called. This function handles socket to be closed and deleted internally. The socket must be in a CLOSED state or in the process of disconnecting before the port is released. Otherwise, an error is returned. Finally, if the application no longer needs the client socket, the vTaskDelete() function is called to delete the socket.

```
void tcp_client_sample()
{
    ...
    close(socket_fd);

end_of_task:

      PRINTF("[%s] End of TCP Client sample\r\n", __func__);
      vTaskDelete(NULL);
      return ;
}
```

9.3 TCP Client in DPM

This section describes how the TCP client in the DPM sample application is built and works. The TCP client in the Dynamic Power Management (DPM) sample application is an example of the simplest TCP echo client application in DPM mode. The DA16200 SDK can work in DPM mode. The user application requires an additional operation to work in DPM mode. The DA16200 SDK provides the DPM manager for the user network application. The DPM manager supports users to develop and manage a network application in Non-DPM and DPM modes.

9.3.1 How to Run

1. Run a socket application on the peer laptop (see Section 9.1.2) and open a TCP server socket with port number 10192.
2. In the e²studio, import a project for the TCP client in the DPM sample application as follows:
   `~/SDK/apps/common/examples/Network/TCP_Client_DPM/projects/da16200`
   - Build the DA16200 SDK, download the RTOS image to the DA16200 EVB, and reboot.
3. Use the console command to set up the Wi-Fi station interface.
4. To set the IP address and the port for the peer application (TCP Server) in the TCP Client Sample, do one of the following:
   - Edit the source code:
     ~/SDK/apps/common/examples/Network/TCP_Client_DPM/src/tcp_client_dpm_sample.c

     #define define TCP_CLIENT_DPM_SAMPLE_DEF_SERVER_IP "192.168.0.11"
     #define TCP_CLIENT_DPM_SAMPLE_DEF_SERVER_PORT TCP_CLI_TEST_PORT
   - Use the DA16200 console to save the values in NVRAM:

```
[/DA16200] # nvram.setenv TCPC_SERVER_IP 192.168.0.11
[/DA16200] # nvram.setenv TCPC_SERVER_PORT 10192
[/DA16200] # reboot
```

After a connection is made to a Wi-Fi AP, the example of connecting to the peer application (TCP Server).

9.3.2 How It Works

The DA16200 TCP Client in the DPM sample application is a simple echo message. When the TCP server sends a message, then the DA16200 TCP client echoes that message to the TCP server.

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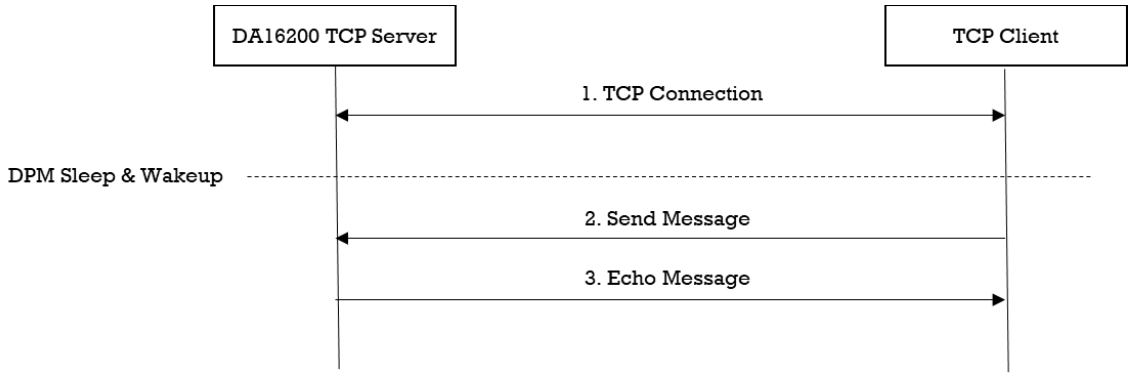

Figure 19: Workflow of TCP Client in DPM

9.3.3 Sample Code

9.3.3.1 Registration

The TCP client in the DPM sample application works in DPM mode. The basic code is similar to the TCP client sample application. There are two differences from the TCP client sample application:

- An initial callback function is added, named tc9p_client_dpm_sample_wakeup_callback() in the code. The callback is called when the DPM state changes from sleep to wake-up
- Additional user configuration can be stored in RTM

In this sample, the TCP server information is stored.

```
void tcp_client_dpm_sample_init_user_config(dpm_user_config_t *user_config)
{
        const int session_idx = 0;

        //Set Boot init callback
        user_config->bootInitCallback = tcp_client_dpm_sample_init_callback;

        //Set DPM wakeup init callback
        user_config->wakeupInitCallback = tcp_client_dpm_sample_wakeup_callback;

        //Set External wakeup callback
        user_config->externWakeupCallback = tcp_client_dpm_sample_external_callback;

        //Set Error callback
        user_config->errorCallback = tcp_client_dpm_sample_error_callback;

        //Set session type(TCP Client)
        user_config->sessionConfig[session_idx].sessionType = REG_TYPE_TCP_CLIENT;

        //Set local port
        user_config->sessionConfig[session_idx].sessionMyPort =
        TCP_CLIENT_DPM_SAMPLE_DEF_CLIENT_PORT;

        //Set server IP address
        memcpy(user_config->sessionConfig[session_idx].sessionServerIp,
           srv_info.ip_addr, strlen(srv_info.ip_addr));

        //Set server port
        user_config->sessionConfig[session_idx].sessionServerPort = srv_info.port;

        //Set Connection callback
        user_config->sessionConfig[session_idx].sessionConnectCallback =
        tcp_client_dpm_sample_connect_callback;
```


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```
        //Set Recv callback
        user_config->sessionConfig[session_idx].sessionRecvCallback =
        tcp_client_dpm_sample_recv_callback;

        //Set connection retry count
        user_config->sessionConfig[session_idx].sessionConnRetryCnt =
        TCP_CLIENT_DPM_SAMPLE_DEF_MAX_CONNECTION_RETRY;

        //Set connection timeout
        user_config->sessionConfig[session_idx].sessionConnWaitTime =
        TCP_CLIENT_DPM_SAMPLE_DEF_MAX_CONNECTION_TIMEOUT;

        //Set auto reconnection flag
        user_config->sessionConfig[session_idx].sessionAutoReconn = TRUE;

        //Set user configuration
        user_config->ptrDataFromRetentionMemory = (UCHAR *)&srv_info;
        user_config->sizeOfRetentionMemory =
         sizeof(tcp_client_dpm_sample_svr_info_t);

        return ;
}
```

9.3.3.2 Data Transmission

The callback function is called when a TCP packet is received from a TCP server. In this sample, the received data is printed out and an echo message is sent to the TCP server.

```
void tcp_client_dpm_sample_recv_callback(void *sock, UCHAR *rx_buf, UINT rx_len,
                                  ULONG rx_ip, ULONG rx_port)
{
        unsigned char status = pdPASS;

        //Display received packet
        PRINTF(" ==> Received Packet(%ld) \n", rx_len);

        //Echo message
        status = dpm_mng_send_to_session(SESSION1, rx_ip, rx_port,
                                    (char *)rx_buf, rx_len);
        else
        {
             //Display sent packet
             PRINTF(" <== Sent Packet(%ld) \n", rx_len);
        }

        dpm_mng_job_done(); //Done opertaion
}
```

9.4 TCP Server

This section describes how the TCP server sample application is built and works. The TCP server sample application is an example of the simplest TCP echo server application. TCP is one of the main protocols of the Internet protocol suite. It provides a reliable, ordered, and error-checked delivery of a stream of octets (bytes) between applications running on hosts that communicate via an IP network. The DA16200 SDK provides a lwIP's TCP protocol. lwIP is an open-source TCP/IP stack designed for embedded system.

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9.4.1 How to Run

1. In the e²studio, import a project for the TCP Server sample application as follows:
   `~/SDK/apps/common/examples/Network/TCP_Server/projects/da16200`
2. Build the DA16200 SDK, download the RTOS image to the DA16200 EVB, and reboot.
3. To set the port of the TCP Server Sample, do one of the following:
   - Edit the source code:
     `~/SDK/apps/common/examples/Network/TCP_Server/src/tcp_server_sample.c`

     ```
     #define TCP_SERVER_SAMPLE_DEF_SERVER_PORT    TCP_SVR_TEST_PORT
     ```
   - Use the DA16200 console to save the values in NVRAM:

     ```
     [/DA16200] # nvram.setenv TCP_SVR_PORT 10190
     [/DA16200] # reboot
     ```
4. Set up the Wi-Fi station interface using console commands.
5. When connected to the AP, the sample application creates a TCP server socket with port number 10190 and waits for a client connection.
6. Run a socket application on the peer PC (See Section 9.1.2).
7. Open a TCP client socket.

9.4.2 How It Works

The DA16200 TCP server sample application is a simple echo server. When a TCP client sends a message, the DA16200 TCP server echoes that message to the TCP client.

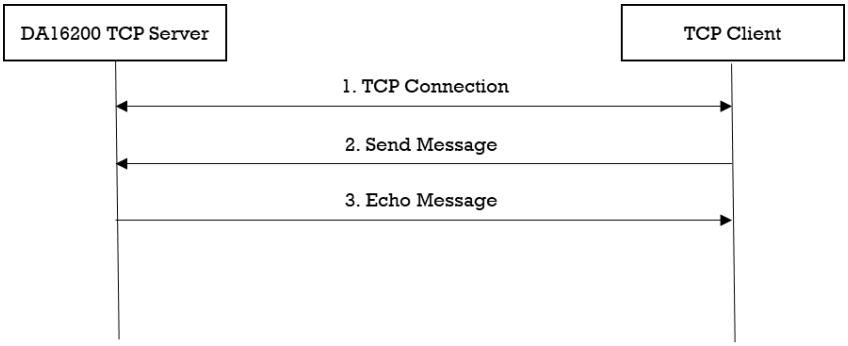

Figure 20: Workflow of TCP Server

9.4.3 Sample Code

The DA16200 SDK provides the lwIP's TCP protocol. This sample application describes how a TCP socket is created, deleted, and configured.

9.4.3.1 Connection

The server waits for a client connection request. Next, the application must create a TCP socket with the socket() service. The server socket must also be set up to listen for connection requests with the listen() service. This service puts the server socket in the LISTEN state and binds the specified server port to the server socket. If the socket connection has already been established, the function simply returns a successful status.

```
void tcp_server_sample()
{
    int ret = 0;
    int listen_sock = -1;
    int client_sock = -1;
```


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```
    struct sockaddr_in server_addr;
    struct sockaddr_in client_addr;

    memset(&server_addr, 0x00, sizeof(struct sockaddr_in));
    memset(&client_addr, 0x00, sizeof(struct sockaddr_in));

    // Create TCP socket
    listen_sock = socket(PF_INET, SOCK_STREAM, 0);
    if (listen_sock < 0) {
        PRINTF("[%s] Failed to create listen socket\r\n", __func__);
        goto end_of_task;
    }

    server_addr.sin_family = AF_INET;
    server_addr.sin_addr.s_addr = htonl(INADDR_ANY);
    server_addr.sin_port = htons(TCP_SERVER_SAMPLE_DEF_PORT);

    // Bind TCP socket
    ret = bind(listen_sock, (struct sockaddr *)&server_addr,
                sizeof(struct sockaddr_in));

    // Listen TCP socket
    ret = listen(listen_sock, TCP_SERVER_SAMPLE_BACKLOG);

    while (1) {
        client_sock = -1;
        memset(&client_addr, 0x00, sizeof(struct sockaddr_in));
        client_addrlen = sizeof(struct sockaddr_in);

        // Accept TCP socket
        client_sock = accept(listen_sock, (struct sockaddr *)&client_addr,
                                          (socklen_t *)&client_addrlen);
        While (1){
        ...
        }
    }
}
```

9.4.3.2 Data Transmission

TCP data is received when function recv() is called. The TCP receive packet process is responsible for handling the various connections and disconnections as well as transmission acknowledgment process.

TCP data is sent when function send() is called. This service first builds a TCP header in the front part of the packet (including the checksum calculation). If the receiver's window size is larger than the data in this packet, the packet is sent on the Internet with the internal IP send routine. Otherwise, the caller may suspend and wait for the receiver`s window size to increase enough for this packet to be sent. At any given time, only one sender may suspend while trying to send TCP data.

```
void tcp_server_sample_run()
{
    ...
    while (NX_TRUE)
    {
        memset(data_buffer, 0x00, sizeof(data_buffer));

        PRINTF("< Read from client: ");
        len = recv(client_sock, data_buffer, sizeof(data_buffer), 0);
        data_buffer[len] = '\0';
        PRINTF("%d bytes read\r\n", len);
```

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```
        PRINTF("> Write to client: ");
        len = send(client_sock, data_buffer, len, 0);
        PRINTF("%d bytes written\r\n", len);
    }
    ...
}
```

9.4.3.3 Disconnection

The connection is closed when function close() is called. This function handles socket to be closed and deleted internally.

```
void tcp_server_sample()
{
    ...
    While (1) {
        Close(client_socket)
        ...
    }

end_of_task:

      PRINTF("[%s] End of TCP Server sample\r\n", __func__);
      close(listen_sock);
      close(client_sock);
      vTaskDelete(NULL);
      return ;
}
```

9.5 TCP Server in DPM

This section describes how the TCP server is built and works in the DPM sample application. The TCP server in the DPM sample application is an example of the simplest TCP echo server application. The DA16200 SDK can work in DPM mode. The user application is required to work in DPM mode. The DA16200 SDK provides the DPM manager for the user network application. The DPM manager supports the user to develop and manage a network application in Non-DPM and DPM modes. The codes are almost the same as for the TCP server example.

9.5.1 How to Run

1. Open the workspace for the TCP Server in DPM sample application as follows:
   - *~/SDK/apps/common/examples/Network/TCP_Server_DPM/projects/da16200*
2. Build the DA16200 SDK, download the RTOS image to the DA16200 EVB, and reboot.
3. To set the port of the TCP Server Sample, do one of the following:
   - Edit the source code:

     ~/SDK/apps/common/examples/Network/TCP_Server_DPM/src/tcp_server_dpm_sample.c

     #define TCP_SERVER_DPM_SAMPLE_DEF_SERVER_PORT TCP_SVR_TEST_PORT
   - Use the DA16200 console to save the values in NVRAM:

     [/DA16200] # nvram.setenv TCP_SVR_PORT 10190

     [/DA16200] # reboot
4. Use the console command to set up the Wi-Fi station interface.
5. When connected to the AP, the sample application creates a TCP server socket with port number 10190 (Default test port number) and waits for a client connection.
6. Run a socket application on the peer PC (See Section 9.1.2).
7. Open a TCP client socket.

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9.5.2 How It Works

The DA16200 TCP server in the DPM sample application is a simple echo server. When a TCP client sends a message, then the DA16200 TCP server echoes that message to the TCP client.

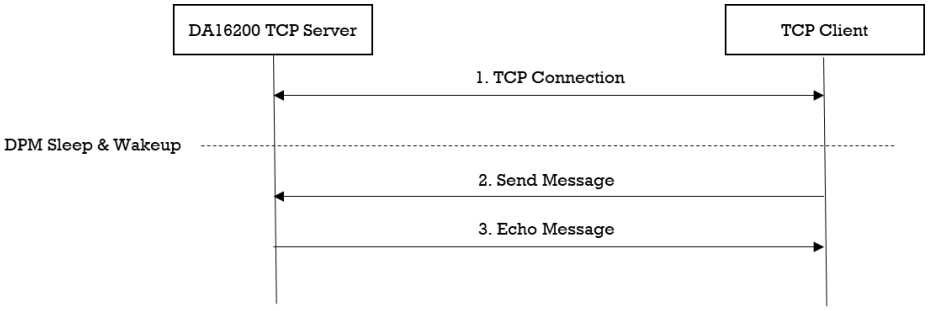

Figure 21: Workflow of TCP Server in DPM

9.5.3 Sample Code

9.5.3.1 Registration

The TCP server in the DPM sample application works in DPM mode. The basic code is similar to the TCP server sample application. There are two differences from the TCP Server sample application:

- An initial callback function is added, named tcp_server_dpm_sample_wakeup_callback() in the code. The callback is called when the DPM state changes from sleep to wake-up
- Additional user configuration can be stored in RTM

In this sample, the TCP server information is stored.

```
void tcp_server_dpm_sample_init_user_config(dpm_user_config_t *user_config)
{
      const int session_idx = 0;

      //Set Boot init callback
      user_config->bootInitCallback = tcp_server_dpm_sample_init_callback;

      //Set DPM wakkup init callback
      user_config->wakeupInitCallback = tcp_server_dpm_sample_wakeup_callback;

      //Set Error callback
      user_config->errorCallback = tcp_server_dpm_sample_error_callback;

      //Set session type(TCP Server)
      user_config->sessionConfig[session_idx].sessionType = REG_TYPE_TCP_SERVER;

      //Set local port
      user_config->sessionConfig[session_idx].sessionMyPort =
       TCP_SERVER_DPM_SAMPLE_DEF_SERVER_PORT;

      //Set Connection callback
      user_config->sessionConfig[session_idx].sessionConnectCallback =
       tcp_server_dpm_sample_connect_callback;

      //Set Recv callback
      user_config->sessionConfig[session_idx].sessionRecvCallback =
       tcp_server_dpm_sample_recv_callback;

      //Set user configuration
      user_config->ptrDataFromRetentionMemory = (UCHAR *)&srv_info;
```

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```
        user_config->sizeOfRetentionMemory = sizeof(tcp_server_dpm_sample_svr_info_t);

        return ;
}
```

9.5.3.2 Data Transmission

The callback function is called when a TCP packet is received from a TCP client. In this sample, the received data is printed out and an echo message is sent to the TCP client.

```
void tcp_server_dpm_sample_recv_callback(void *sock, UCHAR *rx_buf, UINT rx_len,
                                         ULONG rx_ip, ULONG rx_port)
{
        //Display received packet
        PRINTF(" ==> Received Packet(%ld) \n", rx_len);

        //Echo message
        status = dpm_mng_send_to_session(SESSION1, rx_ip, rx_port,
                                         (char *)rx_buf, rx_len);

        //Display sent packet
        PRINTF(" <== Sent Packet(%ld) \n", rx_len);

        dpm_mng_job_done(); //Done opertaion
}
```

9.6 TCP Client with KeepAlive in DPM

This section describes how the TCP client with KeepAlive in the DPM sample application is built and works. The TCP client with KeepAlive in the DPM sample application is an example of the simplest TCP echo client application in DPM mode. The DA16200 SDK can work in DPM mode. The user application is required to work in DPM mode. The DA16200 SDK provides the DPM manager for the user network application. The DPM manager helps users to develop and manage a network application in both Non-DPM and DPM modes.

9.6.1 How to Run

1. Run a socket application on the peer PC (see Section 9.1.2) and open a TCP server socket with port number 10193 (Default TCP Client test port).
2. In the e²studio, import a project for the TCP Client sample application as follows:
   - *~/SDK/apps/common/examples/Network/TCP_Client_KeepAlive_DPM/projects/da16200*
3. Build the DA16200 SDK, download the RTOS image to the DA16200 EVB, and reboot.
4. Use the console command to set up the Wi-Fi station interface.
5. To set the IP address and the port for the peer application (TCP Server) in the TCP Client KA DPM Sample, do one of the following:
   - Edit the source code:

     ~/SDK/apps/common/examples/Network/TCP_Client_KeepAlive_DPM/src/tcp_client_ka_dpm_sample.c

     //Default TCP Server configuration
     #define TCP_CLIENT_KA_DPM_SAMPLE_DEF_SERVER_IP "192.168.0.11"
     #define TCP_CLIENT_KA_DPM_SAMPLE_DEF_SERVER_PORT TCP_CLI_KA_TEST_PORT
   - Use the DA16200 console to save the values in NVRAM:

     [/DA16200] # nvram.setenv TCPC_SERVER_IP 192.168.0.11
     [/DA16200] # nvram.setenv TCPC_SERVER_PORT 10192
     [/DA16200] # reboot

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After a connection is made to a Wi-Fi AP, the example connects to the peer application (TCP Server).

9.6.2 Sample Code

9.6.2.1 Registration

The TCP client with KeepAlive in the DPM sample application works in DPM mode. The basic code is similar to the TCP client with the KeepAlive sample application. The time period is 55 seconds to send a TCP KeepAlive message to the TCP server. Compared to the TCP client in the DPM sample application, there are two differences from the TCP client sample application:

- An initial callback function is added, named tcp_client_ka_dpm_sample_wakeup_callback() in the code. The callback function is called when the DPM state changes from sleep to wake-up
- Additional user configuration can be stored in RTM

In this example, TCP server information is stored.

```
void tcp_client_ka_dpm_sample_init_user_config(dpm_user_config_t *user_config)
{
      const int session_idx = 0;

      //Set Boot init callback
      user_config->bootInitCallback = tcp_client_ka_dpm_sample_init_callback;

      //Set DPM wakeup init callback
      user_config->wakeupInitCallback = tcp_client_ka_dpm_sample_wakeup_callback;

      //Set Error callback
      user_config->errorCallback = tcp_client_ka_dpm_sample_error_callback;

      //Set session type(TCP Client)
      user_config->sessionConfig[session_idx].sessionType = REG_TYPE_TCP_CLIENT;

      //Set local port
      user_config->sessionConfig[session_idx].sessionMyPort =
       TCP_CLIENT_KA_DPM_SAMPLE_DEF_CLIENT_PORT;

      //Set server IP address
      memcpy(user_config->sessionConfig[session_idx].sessionServerIp,
          srv_info.ip_addr, strlen(srv_info.ip_addr));

      //Set server port
      user_config->sessionConfig[session_idx].sessionServerPort = srv_info.port;

      //Set Connection callback
      user_config->sessionConfig[session_idx].sessionConnectCallback =
       tcp_client_ka_dpm_sample_connect_callback;

      //Set Recv callback
      user_config->sessionConfig[session_idx].sessionRecvCallback =
       tcp_client_ka_dpm_sample_recv_callback;

      //Set connection retry count
      user_config->sessionConfig[session_idx].sessionConnRetryCnt =
       TCP_CLIENT_KA_DPM_SAMPLE_DEF_MAX_CONNECTION_RETRY;

      //Set connection timeout
      user_config->sessionConfig[session_idx].sessionConnWaitTime =
       TCP_CLIENT_KA_DPM_SAMPLE_DEF_MAX_CONNECTION_TIMEOUT;
```

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```
        //Set auto reconnection flag
        user_config->sessionConfig[session_idx].sessionAutoReconn = pdTRUE;

        //Set KeepAlive timeout
        user_config->sessionConfig[session_idx].sessionKaInterval =
         TCP_CLIENT_KA_DPM_SAMPLE_DEF_KEEPALIVE_TIMEOUT;

        //Set user configuration
        user_config->ptrDataFromRetentionMemory = (UCHAR *)&srv_info;
        user_config->sizeOfRetentionMemory =
         sizeof(tcp_client_ka_dpm_sample_svr_info_t);

        return ;
}
```

9.6.2.2 Data Transmission

The callback function is called when a TCP packet is received from the TCP server. In this example, the received data is printed out and an echo message is sent to the TCP server.

```
void tcp_client_ka_dpm_sample_recv_callback(void *sock, UCHAR *rx_buf, UINT rx_len,
                                            ULONG rx_ip, ULONG rx_port)
{
        //Display received packet
        PRINTF(" ==> Received Packet(%ld) \n", rx_len);

        //Echo message
        status = dpm_mng_send_to_session(SESSION1, rx_ip, rx_port, (char *)rx_buf,
rx_len);
        else
        {
                //Display sent packet
                PRINTF(" <== Sent Packet(%ld) \n", rx_len);
        }

        dpm_mng_job_done(); //Done opertaion}
}
```

9.6.3 How It Works

The DA16200 TCP Client with KeepAlive in the DPM sample application is a simple echo message. When the TCP server sends a message, then the DA16200 TCP client echoes that message to the TCP server. A periodic TCP KeepAlive message is sent to the TCP server every 55 seconds.

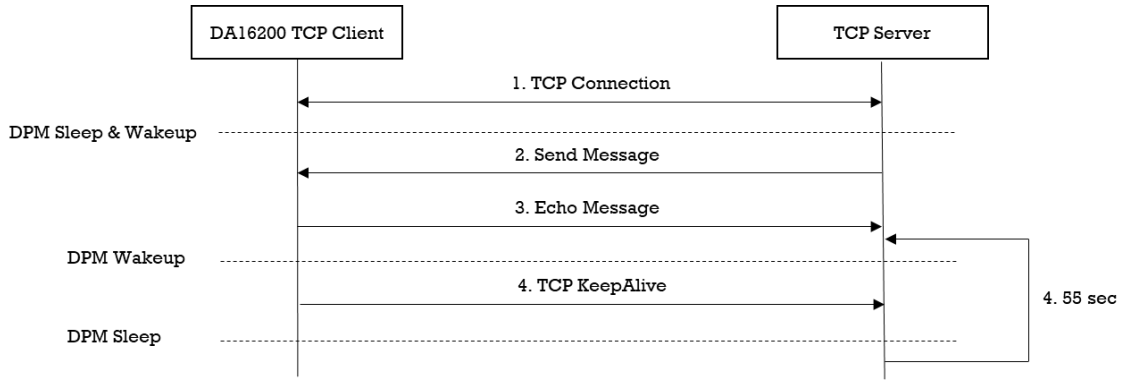

Figure 22: Workflow of TCP Client with KeepAlive in DPM

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9.7 UDP Socket

This section describes how the UDP socket sample application is built and works. The UDP socket sample application is an example of the simplest UDP echo application. UDP is one of the core members of the Internet protocol suite. It uses a simple connectionless communication model with minimum protocol mechanisms. UDP provides checksums for data integrity and port numbers to address different functions at the source and destination of the datagram. Since there is no handshaking, it exposes the user program to all the instability of the underlying network; there is no guarantee of delivery, order, or duplicate protection. The DA16200 SDK provides a lwIP's TCP protocol. lwIP is an open-source TCP/IP stack designed for embedded system.

9.7.1 How to Run

1. Run a socket application on the peer PC (see Section 9.1.2) and open a UDP socket with port number 10195 (default UDP test port).
2. In the e²studio, import a project for the UDP socket sample application as follows:
   - *~/SDK/apps/common/examples/Network/UDP_Socket/projects/da16200*
3. Build the DA16200 SDK, download the RTOS image to the DA16200 EVB, and reboot.
4. Use the console command to set up the Wi-Fi station interface.
5. To set the port number for the peer application (UDP Socket) of the UDP Socket Sample, edit the source code:

   ~/SDK/apps/common/examples/Network/UDP_Socket/src/udp_socket_sample.c

   #define UDP_SOCKET_SAMPLE_DEF_LOCAL_PORT UDP_CLI_TEST_PORT

After a connection is made to a Wi-Fi AP, the example connects to the peer application (UDP Socket).

9.7.2 How It Works

The DA16200 UDP socket sample application is a simple echo server. When a UDP peer sends a message, then the DA16200 UDP socket sample application echoes that message to the UDP peer.

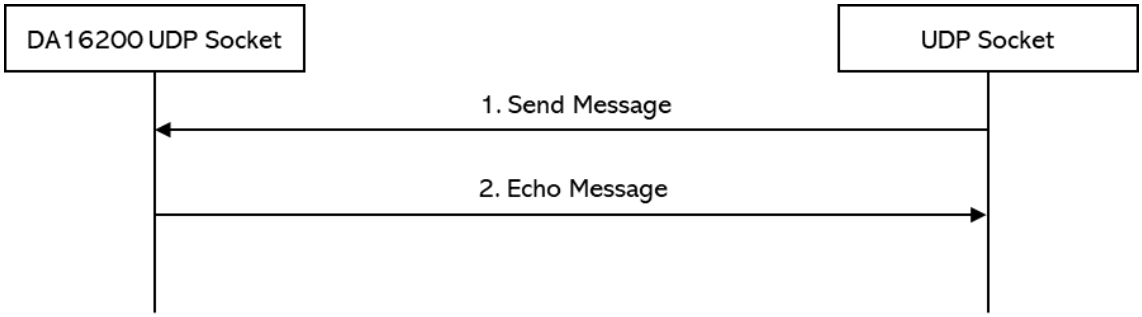

Figure 23: Workflow of UDP Socket

9.7.3 Sample Code

The DA16200 SDK provides the lwIP's UDP protocol. This sample application describes how the UDP socket is created, deleted, and configured.

9.7.3.1 Initialization

A UDP port is a logical end point in the UDP protocol. There are 65,535 valid ports in the UDP component of lwIP, ranging from 1 through 0xFFFF. To send or receive UDP data, the application should first create a UDP socket with function socket(), then bind the UDP socket to the desired port. Next, the application may send and receive data on that socket. The details are as follows:

```
void udp_socket_sample_run()
{
    int sock;
```

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```
        struct sockaddr_in local_addr;
        struct sockaddr_in peer_addr;

        memset(&local_addr, 0x00, sizeof(local_addr));
        memset(&peer_addr, 0x00, sizeof(peer_addr));

        sock = socket(AF_INET, SOCK_DGRAM, 0);
        setsockopt(sock, SOL_SOCKET, SO_REUSEADDR, (const void *)&optval,sizeof(int));

        local_addr.sin_family = AF_INET;
        local_addr.sin_addr.s_addr = htonl(INADDR_ANY);
        local_addr.sin_port = htons(UDP_SOCKET_SAMPLE_PEER_PORT);

        ret = bind(sock, (struct sockaddr *)&local_addr, sizeof(struct sockaddr_in));

      ...
}
```

9.7.3.2 Data Transmission

To receive a UDP packet, function recvfrom() is called. The socket receive function delivers the oldest packet on the socket's receive queue. To send UDP data, function sendto() is called. This service puts a UDP header in the front part of the packet and sends the packet on the Internet with the internal IP send routine.

```
void udp_socket_sample_run()
{
    ...
     while (1) {
         memset(&peer_addr, 0x00, sizeof(struct sockaddr_in));
         memset(data_buffer, 0x00, sizeof(data_buffer));

         PRINTF("< Read from peer: ");

         ret = recvfrom(sock, data_buffer, sizeof(data_buffer), 0,
                        (struct sockaddr *)&peer_addr, (socklen_t *)&addr_len);
         if (ret > 0) {
             len = ret;
             PRINTF("%d bytes read(%d.%d.%d.%d:%d)\r\n", len,
                       (ntohl(peer_addr.sin_addr.s_addr) >> 24) & 0xff,
                       (ntohl(peer_addr.sin_addr.s_addr) >> 16) & 0xff,
                       (ntohl(peer_addr.sin_addr.s_addr) >>  8) & 0xff,
                       (ntohl(peer_addr.sin_addr.s_addr)      ) & 0xff,
                       (ntohs(peer_addr.sin_port)));

             PRINTF("> Write to peer: ");
             ret = sendto(sock, data_buffer, len, 0,
                          (struct sockaddr *)&peer_addr, addr_len);
             PRINTF("%d bytes written(%d.%d.%d.%d:%d)\r\n", len,
                       (ntohl(peer_addr.sin_addr.s_addr) >> 24) & 0xff,
                       (ntohl(peer_addr.sin_addr.s_addr) >> 16) & 0xff,
                       (ntohl(peer_addr.sin_addr.s_addr) >>  8) & 0xff,
                       (ntohl(peer_addr.sin_addr.s_addr)      ) & 0xff,
                       (ntohs(peer_addr.sin_port)));
         }
     }
}
```

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9.8 UDP Server in DPM

This section describes how the UDP server in the DPM sample application is built and works. The UDP server in the DPM sample application is an example of the simplest UDP echo application in DPM mode. The DA16200 SDK can work in DPM mode. The DPM manager of the DA16200 SDK is helpful for the user to develop and manage a UDP server socket application in Non-DPM and DPM modes.

9.8.1 How to Run

1. Run a socket application on the peer PC (see Section 9.1.2) and open a UDP socket with port number 10194 (Default UDP test port).
2. In the e²studio, import a project for the UDP Server DPM sample application as follows:
   - *~/SDK/apps/common/examples/Network/UDP_Server_DPM/projects/da16200*
3. Build the DA16200 SDK, download the RTOS image to the DA16200 EVB, and reboot.
4. Use the console command to set up the Wi-Fi station interface.
5. To set the port number for the peer application (UDP Client) of the UDP Server DPM Sample, edit the source code:
   ~/SDK/apps/common/examples/Network/UDP_Server_DPM/src/udp_server_dpm_sample.c
   #define UDP_SERVER_DPM_SAMPLE_DEF_SERVER_PORT UDP_SVR_TEST_PORT

After a connection is made to a Wi-Fi AP, the example connects to the peer application (UDP Client).

9.8.2 How It Works

The DA16200 UDP Server in the DPM sample application is a simple echo server. When the peer's UDP application sends a message, the DA16200 UDP server echoes that message to the peer.

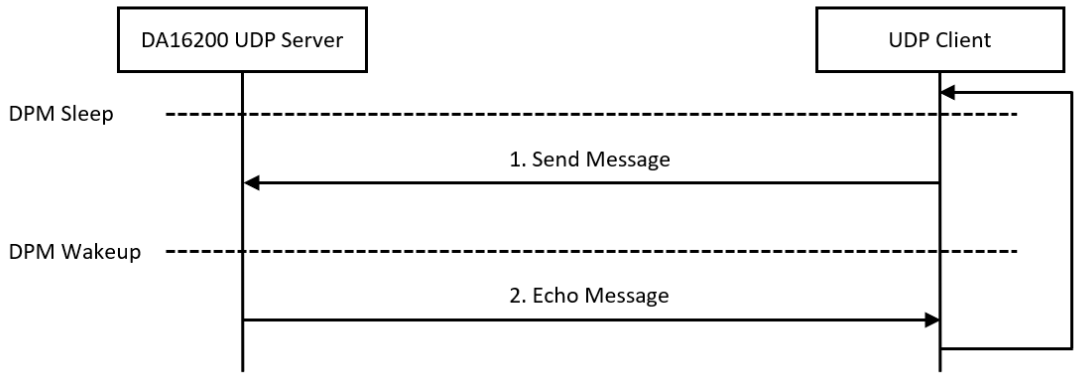

Figure 24: Workflow of UDP Server in DPM

9.8.3 Sample Code

9.8.3.1 Registration

The UDP server in the DPM sample application works in DPM mode. The basic code is similar to the UDP server sample application. The only differences are as below:

- An initial callback function is added, named udp_server_dpm_sample_wakeup_callback() in the code. The callback function is called when the DPM state changes from sleep to wake-up
- Additional user configuration can be stored in RTM

In this sample, the peer's UDP socket port number will be stored.

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```
void udp_server_dpm_sample_init_user_config(dpm_user_config_t *user_config)
{
      const int session_idx = 0;

      //Set Boot init callback
      user_config->bootInitCallback = udp_server_dpm_sample_init_callback;

      //Set DPM wakkup init callback
      user_config->wakeupInitCallback = udp_server_dpm_sample_wakeup_callback;

      //Set Error callback
      user_config->errorCallback = udp_server_dpm_sample_error_callback;

      //Set session type(UDP Server)
      user_config->sessionConfig[session_idx].sessionType = REG_TYPE_UDP_SERVER;

      //Set local port
      user_config->sessionConfig[session_idx].sessionMyPort =
       UDP_SERVER_DPM_SAMPLE_DEF_SERVER_PORT;

      //Set Connection callback
      user_config->sessionConfig[session_idx].sessionConnectCallback =
       udp_server_dpm_sample_connect_callback;

      //Set Recv callback
      user_config->sessionConfig[session_idx].sessionRecvCallback =
       udp_server_dpm_sample_recv_callback;

      //Set secure mode
      user_config->sessionConfig[session_idx].supportSecure = pdFALSE;

      //Set user configuration
      user_config->ptrDataFromRetentionMemory = (UCHAR *)&srv_info;
      user_config->sizeOfRetentionMemory = sizeof(udp_server_dpm_sample_svr_info_t);

      return ;
}
```

9.8.3.2 Data Transmission

The callback function is called when a UDP packet is received from the peer's UDP socket application. In this example, the received data is printed out and an echo message is sent to the peer's UDP socket application.

```
void udp_server_dpm_sample_recv_callback(void *sock, UCHAR *rx_buf, UINT rx_len,
                                         ULONG rx_ip, ULONG rx_port)
{
      //Display received packet
      PRINTF(" =====> Received Packet(%ld) \n", rx_len);

      //Echo message
      status = dpm_mng_send_to_session(SESSION1, rx_ip, rx_port,
                                       (char *)rx_buf, rx_len);
      if (status) {
            PRINTF(RED_COLOR " [%s] Fail send data(session%d,0x%x) \n" CLEAR_COLOR,
                  __func__, SESSION1, status);
      } else {
            //Display sent packet
            PRINTF(" <== Sent Packet(%ld) \n", rx_len);
      }
      dpm_mng_job_done(); //Done opertaion }
```

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9.9 UDP Client in DPM

This section describes how the UDP client in the DPM sample application is built and works. The UDP client in the DPM sample application is an example of the simplest UDP echo application in DPM mode. The DA16200 SDK can work in DPM mode. The user application requires an additional operation to work in DPM mode. The DPM manager of the DA16200 SDK is helpful for the user to develop and manage a UDP client socket application in both Non-DPM and DPM modes.

9.9.1 How to Run

1. Run a socket application on the peer PC (see Section 9.1.2) and open a UDP socket with port number 10195 (Default UDP test port).
2. In the e²studio, import a project for the UDP Client DPM sample application as follows:
   - *~/SDK/apps/common/examples/Network/UDP_Client_DPM/projects/da16200*
3. Build the DA16200 SDK, download the RTOS image to the DA16200 EVB, and reboot.
4. Use the console command to set up the Wi-Fi station interface.
5. To set the port number for the peer application (UDP Server) of the UDP Client DPM Sample, edit the source code:

   ~/SDK/apps/common/examples/Network/ UDP_Client_DPM/src/udp_client_dpm_sample.c

   #define UDP_CLIENT_DPM_SAMPLE_DEF_SERVER_PORT UDP_CLI_TEST_PORT

After a connection is made to a Wi-Fi AP, the example connects to the peer application (UDP Server).

9.9.2 How It Works

The DA16200 UDP Client in the DPM sample application is a simple echo message. When a peer's UDP application sends a message, then the DA16200 UDP client echoes that message to the peer.

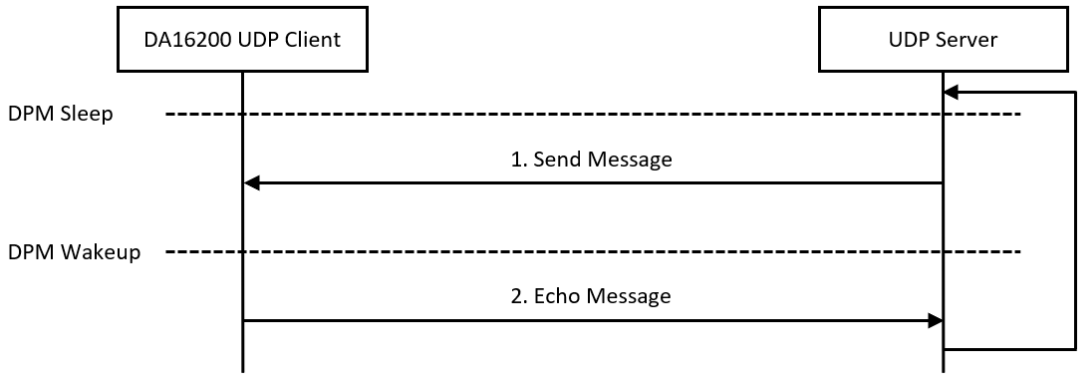

Figure 25: Workflow of UDP Client in DPM

9.9.3 Sample Code

9.9.3.1 Registration

The UDP client in the DPM sample application works in DPM mode. The basic code is similar to the UDP client sample application. There are two differences from the UDP client sample application:

- An initial callback function is added, named udp_client_dpm_sample_wakeup_callback() in the code. The function is called when the DPM state changes from sleep to wake-up
- Additional user configuration can be stored in RTM

In this example, the peer's UDP IP address and port number are stored.

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```
void udp_client_dpm_sample_init_user_config(dpm_user_config_t *user_config)
{
      const int session_idx = 0;

      //Set Boot init callback
      user_config->bootInitCallback = udp_client_dpm_sample_init_callback;

      //Set DPM wakeup init callback
      user_config->wakeupInitCallback = udp_client_dpm_sample_wakeup_callback;

      //Set Error callback
      user_config->errorCallback = udp_client_dpm_sample_error_callback;

      //Set session type(UDP Client)
      user_config->sessionConfig[session_idx].sessionType = REG_TYPE_UDP_CLIENT;

      //Set local port
      user_config->sessionConfig[session_idx].sessionMyPort =
       UDP_CLIENT_DPM_SAMPLE_DEF_CLIENT_PORT;

      //Set server IP address
      memcpy(user_config->sessionConfig[session_idx].sessionServerIp,
          srv_info.ip_addr, strlen(srv_info.ip_addr));

      //Set server port
      user_config->sessionConfig[session_idx].sessionServerPort = srv_info.port;

      //Set Connection callback
      user_config->sessionConfig[session_idx].sessionConnectCallback =
       udp_client_dpm_sample_connect_callback;

      //Set Recv callback
      user_config->sessionConfig[session_idx].sessionRecvCallback =
       udp_client_dpm_sample_recv_callback;

      //Set user configuration
      user_config->ptrDataFromRetentionMemory = (UCHAR *)&srv_info;
      user_config->sizeOfRetentionMemory = sizeof(udp_client_dpm_sample_svr_info_t);

      return ;
}
```

9.9.3.2 Data Transmission

The callback function is called when a UDP packet is received from the peer's UDP socket application. In this example, the received data is printed out and an echo message is sent to the peer's UDP socket application.

```
void udp_client_dpm_sample_recv_callback(void *sock, UCHAR *rx_buf, UINT rx_len,
                                         ULONG rx_ip, ULONG rx_port)
{
      //Display received packet
      PRINTF(" ==> Received Packet(%ld) \n", rx_len);

      status = dpm_mng_send_to_session(SESSION1, 0, 0, (char *)rx_buf, rx_len);
      if (status) {
          PRINTF(RED_COLOR " [%s] Fail send data(session%d,0x%x) \n" CLEAR_COLOR,
                 __func__, SESSION1, status);
      } else {
          //Display sent packet
          PRINTF(" <== Sent Packet(%ld) \n", rx_len);
```

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```
        }

        dpm_mng_job_done(); //Done opertaion
    }
```

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10 Network Examples: Security

10.1 Peer Application

The examples in this section require a peer device (PC/Laptop) connected to the same AP running a (D)TLS test application.

10.1.1 Peer Application Examples

There are many (D)TLS counter applications available. In this section, we use a self-implemented (D)TLS counter application to demonstrate these sample applications. It is based on the cryptography APIs of the Bouncy Castle (https://www.bouncycastle.org/java.html). These examples were written and tested on Windows and might be different than the local environment. Use them as reference for testing TLS/DTLS server or client.

10.1.1.1 TLS Server

The TLS server application is for the DA16200 TLS client sample application. It runs with a default port number (10196) and waits for a TLS client to connect, as shown in Figure 26. One TLS client connection is allowed, and no client certificate is required during the TLS handshake. If the TLS session is established successfully, the TLS server application sends a message per five seconds periodically.

```
C:\Samples>tls_server.exe
*****************************************************************
* TLS Server
* ver. 1.0
* Usage: tls_server.exe [Port]
*****************************************************************

Bind on tcp/192.168.0.11:10196
```

Figure 26: Start of TLS Server Application

10.1.1.2 TLS Client

The TLS client application is for the DA16200 TLS server sample application. It runs with default TLS server information. The IP address is 192.168.0.2 and the port number is 10197. The TLS client tries to connect to the DA16200 TLS server sample application as shown in Figure 27. If a TLS session is established successfully, the TLS client application sends a message per 5 seconds periodically.

Usage: tls_client.exe [TLS server IP address] [Port number]

```
C:\Samples>tls_client.exe
*****************************************************************
* TLS Client
* ver. 1.0
* Usage: tls_client.exe [TLS Server IP Address] [Port]
*****************************************************************

Server IP Address: 192.168.0.2
Server Port: 10197
```

Figure 27: Start of TLS Client Application

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If the TLS client application cannot find a DA16200 TLS server, an exception occurs with a timeout message as shown in Figure 28.

```
C:\Samples>tls_client.exe
*************************************************************
* TLS Client
* ver. 1.0
* Usage: tls_client.exe [TLS Server IP Address] [Port]
*************************************************************

Server IP Address: 192.168.0.2
Server Port: 10197
Exception in thread "main" java.net.ConnectException: Connection timed out: connect
        at java.net.DualStackPlainSocketImpl.connect0(Native Method)
        at java.net.DualStackPlainSocketImpl.socketConnect(DualStackPlainSocketImpl.java:79)
        at java.net.AbstractPlainSocketImpl.doConnect(AbstractPlainSocketImpl.java:350)
        at java.net.AbstractPlainSocketImpl.connectToAddress(AbstractPlainSocketImpl.java:206)
        at java.net.AbstractPlainSocketImpl.connect(AbstractPlainSocketImpl.java:188)
        at java.net.PlainSocketImpl.connect(PlainSocketImpl.java:172)
        at java.net.SocksSocketImpl.connect(SocksSocketImpl.java:392)
        at java.net.Socket.connect(Socket.java:589)
        at java.net.Socket.connect(Socket.java:538)
        at java.net.Socket.<init>(Socket.java:434)
        at java.net.Socket.<init>(Socket.java:244)
        at da16200_tls_client_sample.TLSEchoClient.openTlsConnection(TLSEchoClient.java:83)
        at da16200_tls_client_sample.TLSEchoClient.main(TLSEchoClient.java:57)
```

Figure 28: Timeout of TLS Client Application

10.1.1.3 DTLS Server

The DTLS server application is for the DA16200 DTLS client sample application. It runs with a default port number (10199) and waits for the DTLS client to connect, as shown in Figure 29. A client certificate is not required during the DTLS handshake. If a DTLS session is established successfully, the DTLS server application sends a message per five seconds periodically.

```
C:\Samples>dtls_server.exe
*****************************************************************
* DTLS Server
* ver. 1.0
* Usage: dtls_server.exe [Port]
*****************************************************************

Bind on udp/192.168.0.11:10199
```

Figure 29: Start of DTLS Server Application

10.1.1.4 DTLS Client

The Datagram Transport Layer Security (DTLS) client application is for the DA16200 DTLS server sample application. It runs with default DTLS server information. The IP address is 192.168.0.2 and the port number is 10199. The DTLS client tries to connect to the DA16200 DTLS server sample application as shown in Figure 30. If a DTLS session is established successfully, the DTLS client application sends a message per five seconds periodically.

Usage: dtls_client.exe [DTLS server IP address] [Port number]

```
C:\Samples>dtls_client.exe
*****************************************************************
* DTLS Client
* ver. 1.0
* Usage: dtls_client.exe [DTLS Server IP Address] [Port]
*****************************************************************

Server IP Address: 192.168.0.2
Server Port: 10199
```

Figure 30: Start of DTLS Client Application

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10.2 TLS Server

This section describes how the TLS server sample application is built and works. The TLS server sample application is an example of the simplest TLS echo server application. Transport Layer Security (TLS) is a cryptographic protocol designed to provide communication security over a computer network. The DA16200 SDK provides an SSL library, called "mbedTLS", on the secure H/W engine to support the TLS protocol. "MbedTLS" is one of the popular SSL libraries. It is helpful to easily develop a network application with a TLS protocol.

10.2.1 How to Run

1. In the e²studio, import a project for the TLS Server sample application as follows:
   - *~/SDK/apps/common/examples/Network/TLS_Server/projects/da16200*
2. Build the DA16200 SDK, download the RTOS image to the DA16200 EVB, and reboot.
3. Use the console command to set up the Wi-Fi station interface.
4. After a connection is made to an AP, the sample application creates a TLS server socket with port number 10197 and waits for a client connection.
5. Run a TLS client application on the peer PC.

10.2.2 How It Works

The DA16200 TLS Server sample is a simple echo server. When a TLS client sends a message, the DA16200 TLS server echoes that message to the TLS client.

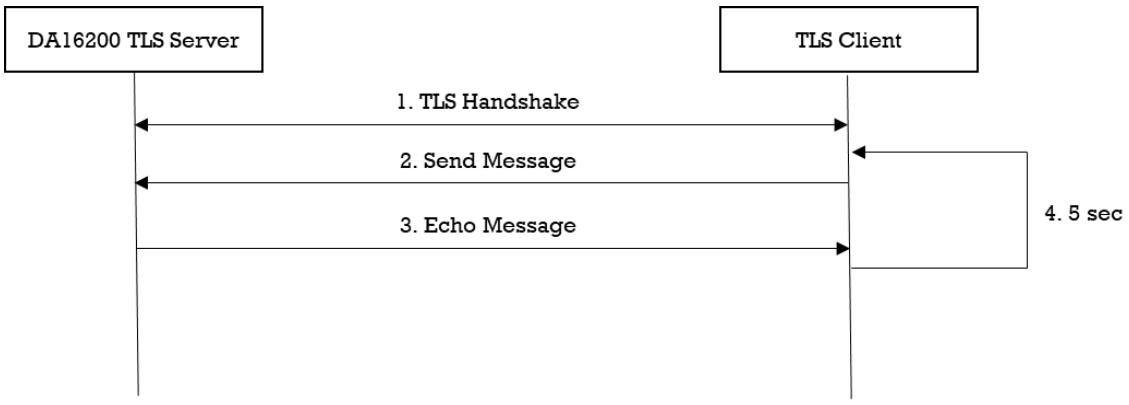

Figure 31: Workflow of TLS Server

10.2.3 Sample Code

The DA16200 SDK provides the "mbedTLS" library. It describes how the TLS server is implemented with an "mbedTLS" library and a socket library.

10.2.3.1 Initialization

The DA16200 secure H/W engine has to be initialized with da16x_secure_module_init() before the TLS context is initialized. To set up a TLS session, initialization functions are called as follows:

```
void tls_server_sample(void *param)
{
    ...

    //Init session
    mbedtls_net_init(&listen_ctx);
    mbedtls_net_init(&client_ctx);

    //Init SSL context
    mbedtls_ssl_init(&ssl_ctx);
```

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```
//Init SSL config
mbedtls_ssl_config_init(&ssl_conf);

//Init CTR-DRBG context
mbedtls_ctr_drbg_init(&ctr_drbg);

//Init Entropy context
mbedtls_entropy_init(&entropy);

//Init Certificate context
mbedtls_x509_crt_init(&cert);

//Init Private key context
mbedtls_pk_init(&pkey);

//Init Private key context for ALT
mbedtls_pk_init(&pkey_alt);

//Parse certificate
ret = mbedtls_x509_crt_parse(&cert, tls_server_sample_cert,
                                        tls_server_sample_cert_len);
//Parse private key
ret = mbedtls_pk_parse_key(&pkey, tls_server_sample_key,
                                     tls_server_sample_key_len, NULL, 0);

snprintf(str_port, sizeof(str_port), "%d", TLS_SERVER_SAMPLE_DEF_PORT);
ret = mbedtls_net_bind(&listen_ctx, NULL, str_port, MBEDTLS_NET_PROTO_TCP);

ret = mbedtls_ctr_drbg_seed(&ctr_drbg, mbedtls_entropy_func, &entropy,
                            (const unsigned char *)pers, strlen(pers));

//Set default configuration
ret = mbedtls_ssl_config_defaults(&ssl_conf, MBEDTLS_SSL_IS_SERVER,
                  MBEDTLS_SSL_TRANSPORT_STREAM, MBEDTLS_SSL_PRESET_DEFAULT);

mbedtls_ssl_conf_rng(&ssl_conf, mbedtls_ctr_drbg_random, &ctr_drbg);

//Import certificate & private key
if (mbedtls_pk_get_type(&pkey) == MBEDTLS_PK_RSA) {
    ret = mbedtls_pk_setup_rsa_alt(&pkey_alt,
                                   (void *)mbedtls_pk_rsa(pkey),
                                    tls_server_sample_rsa_decrypt_func,
                                    tls_server_sample_rsa_sign_func,
                                    tls_server_sample_rsa_key_len_func);

    ret = mbedtls_ssl_conf_own_cert(&ssl_conf, &cert, &pkey_alt);
    if (ret) {
        PRINTF("\r\n[%s] Failed to set certificate(0x%x)\r\n", __func__, -ret);
        goto end_of_task;
    }
} else {
    ret = mbedtls_ssl_conf_own_cert(&ssl_conf, &cert, &pkey);
    if (ret) {
        PRINTF("\r\n[%s] Failed to set certificate(0x%x)\r\n", __func__, -ret);
        goto end_of_task;
    }
}
//Don't care verificate of peer certificate
mbedtls_ssl_conf_authmode(&ssl_conf, MBEDTLS_SSL_VERIFY_NONE);
```

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```
      //Set up an SSL context for use.
      ret = mbedtls_ssl_setup(&ssl_ctx, &ssl_conf);

reset:
     ...
     mbedtls_ssl_set_bio(&ssl_ctx, &client_ctx, mbedtls_net_send, mbedtls_net_recv,
NULL);
     ...
}
```

10.2.3.2 TLS Handshake

TLS is an encryption protocol designed to secure network communication. A TLS handshake is the process of initiating a communication session that uses TLS encryption. To do a TLS handshake, function mbedtls_ssl_handshake() is called. If an error occurred during the TLS handshake, the API returns a specific error code. If a TLS session is established successfully, the API returns 0. The details are as follows:

```
void tls_server_sample(void *param)
{
    ...
reset:
    ...
   while ((ret = mbedtls_ssl_handshake(&ssl_ctx)) != 0) {
     if ((ret != MBEDTLS_ERR_SSL_WANT_READ) && (ret != MBEDTLS_ERR_SSL_WANT_WRITE)){
         PRINTF("\r\n[%s] Failed to do handshake(0x%x)\r\n", __func__, -ret);
         goto reset;
      }
   }
      ...
 }
```

10.2.3.3 Data Transmission

Encryption scrambles data so that only authorized parties can understand the information. While a TLS session is established, all application data must be encrypted to transfer application data. “MbedTLS” provides specific APIs to help encrypt and decrypt data. To write application data, function mbedtls_ssl_write() of the “mbedTLS” library is called. The details are as follows:

```
void tls_server_sample(void *param)
{
    ...
reset:
    ...
    do {
        ...
        while ((ret = mbedtls_ssl_write(&ssl_ctx, data_buffer, len)) <= 0) {
            switch (ret) {
                case MBEDTLS_ERR_SSL_WANT_READ:
                case MBEDTLS_ERR_SSL_WANT_WRITE:
                    PRINTF("\r\nNeed more data - mbedtls_ssl_write(0x%x)\r\n", -ret);
                    continue;
                case MBEDTLS_ERR_SSL_PEER_CLOSE_NOTIFY:
                    PRINTF("\r\nConnection was closed gracefully\r\n");
                    break;
                case MBEDTLS_ERR_NET_CONN_RESET:
                    PRINTF("\r\nConnection was reset by peer\r\n");
                    break;
                default:
                    PRINTF("Failed to write data(0x%x)\r\n", -ret);
                    break;
```

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```
            }
            break;
        }
    }
    ...
}
```

To read application data, function mbedtls_ssl_read() of the "mbedTLS" library is called. In this sample, this function is called in tls_server_sample(). The details are as follows:

```
void tls_server_sample(void *param)
{
    ...
reset:
    ...
    do {
        len = sizeof(data_buffer) - 1;
        memset(data_buffer, 0x00, sizeof(data_buffer));

        PRINTF("< Read from client: ");

        ret = mbedtls_ssl_read(&ssl_ctx, data_buffer, len);
        if (ret <= 0) {
            switch (ret) {
                case MBEDTLS_ERR_SSL_WANT_READ:
                case MBEDTLS_ERR_SSL_WANT_WRITE:
                    PRINTF("\r\nNeed more data - mbedtls_ssl_write(0x%x)\r\n", -ret);
                    continue;
                case MBEDTLS_ERR_SSL_PEER_CLOSE_NOTIFY:
                    PRINTF("\r\nConnection was closed gracefully\r\n");
                    break;
                case MBEDTLS_ERR_NET_CONN_RESET:
                    PRINTF("\r\nConnection was reset by peer\r\n");
                    break;
                default:
                    PRINTF("\r\nFailed to read data(0x%x)\r\n", -ret);
                    break;
            }
            break;
        }

        len = ret;
        PRINTF("%d bytes read\r\n", len);

        while ((ret = mbedtls_ssl_write(&ssl_ctx, data_buffer, len)) <= 0) {
            ...
        }
    }
    ...
}
```

10.3 TLS Server in DPM

This section describes how the TLS server in the DPM sample application is built and works. The TLS server in the DPM sample application is an example of the simplest TLS echo server application. TLS is a set of cryptographic protocols designed to provide secured communication over a computer network. The DA16200 SDK can work in DPM mode. The user application requires an additional operation to work in DPM mode. The DA16200 SDK provides a DPM manager for the user

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network application. The DPM manager supports users to develop and manage a TLS network application in Non-DPM and DPM modes.

10.3.1 How to Run

1. In the e²studio, import a project for the TLS Server in the DPM sample application as follows:
   - *~/SDK/apps/common/examples/Network/TLS_Server_DPM/projects/da16200*
2. Build the DA16200 SDK, download the RTOS image to the DA16200 EVB, and reboot.
3. Use the console command to set up the Wi-Fi station interface.
4. After a connection is made to an AP, the example application creates a TLS server socket with port number 10197 and waits for a client connection.
5. Run a TLS client application on the peer PC.

10.3.2 How It Works

The DA16200 TLS Server in the DPM sample is a simple echo server. When a TLS client sends a message, then the DA16200 TLS server echoes that message to the TLS client. The DA16200 TLS server takes time to wait to establish a TLS session.

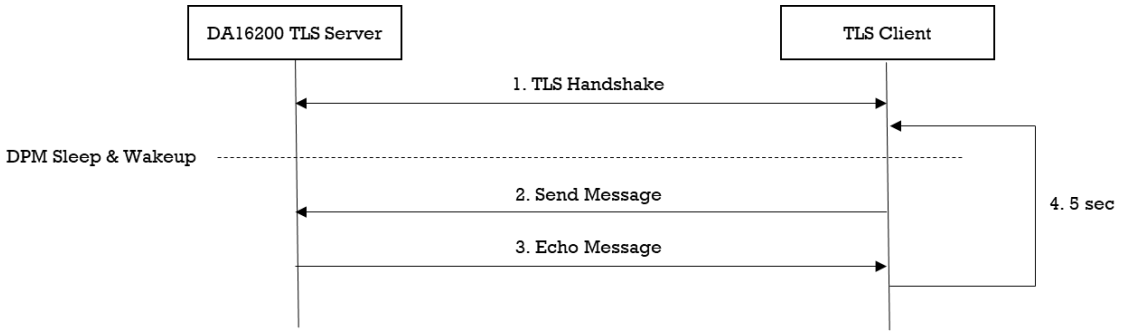

Figure 32: Workflow of TLS Server in DPM

10.3.3 Sample Code

10.3.3.1 Registration

The TLS server in the DPM sample application works in DPM mode. The basic code is similar to the TLS server sample application. There are two differences with the TLS Server sample application:

- An initial callback function is added, named tls_server_dpm_sample_wakeup_callback() in the code. The function is called when the DPM state changes from sleep to wake-up
- Additional user configuration can be stored in RTM

In this sample, the TLS server information is stored.

```
void tls_server_dpm_sample_init_user_config(dpm_user_config_t *user_config)
{
      const int session_idx = 0;

      //Set Boot init callback
      user_config->bootInitCallback = tls_server_dpm_sample_init_callback;

      //Set DPM wakkup init callback
      user_config->wakeupInitCallback = tls_server_dpm_sample_wakeup_callback;

      //Set Error callback
      user_config->errorCallback = tls_server_dpm_sample_error_callback;

      //Set session type(TCP Server)
```

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```
        user_config->sessionConfig[session_idx].sessionType = REG_TYPE_TCP_SERVER;

        //Set local port
        user_config->sessionConfig[session_idx].sessionMyPort =
         TLS_SERVER_DPM_SAMPLE_DEF_SERVER_PORT;

        //Set Connection callback
        user_config->sessionConfig[session_idx].sessionConnectCallback =
         tls_server_dpm_sample_connect_callback;

        //Set Recv callback
        user_config->sessionConfig[session_idx].sessionRecvCallback =
         tls_server_dpm_sample_recv_callback;

        //Set secure mode
        user_config->sessionConfig[session_idx].supportSecure = pdTRUE;

        //Set secure setup callback
        user_config->sessionConfig[session_idx].sessionSetupSecureCallback =
         tls_server_dpm_sample_secure_callback;

        //Set user configuration
        user_config->ptrDataFromRetentionMemory = (UCHAR *)&srv_info;
        user_config->sizeOfRetentionMemory = sizeof(tls_server_dpm_sample_svr_info_t);

        return ;
}
```

10.3.3.2 TLS Setup

To establish a TLS session, TLS should be set up. DA16200 includes the “mbedTLS” library to provide the TLS protocol. Most APIs that are related to the TLS protocol are based on the “mbedTLS” library. TLS is set up by sessionSetupSecureCallback function. The details are as follows.

```
void tls_server_dpm_sample_secure_callback(void *config)
{
        const char *pers = "tls_server_dpm_sample";
        SECURE_INFO_T *secure_config = (SECURE_INFO_T *)config;

        ret = mbedtls_ssl_config_defaults(secure_config->ssl_conf,
                                          MBEDTLS_SSL_IS_SERVER,
                                          MBEDTLS_SSL_TRANSPORT_STREAM,
                                          MBEDTLS_SSL_PRESET_DEFAULT);

        //import test certificate
        ret = mbedtls_x509_crt_parse(secure_config->cert_crt,
                                     tls_server_dpm_sample_cert,
                                     tls_server_dpm_sample_cert_len);

        ret = mbedtls_pk_parse_key(secure_config->pkey_ctx,
                                   tls_server_dpm_sample_key,
                                   tls_server_dpm_sample_key_len,
                                   NULL, 0);

        if (mbedtls_pk_get_type(secure_config->pkey_ctx) == MBEDTLS_PK_RSA) {
            ret = mbedtls_pk_setup_rsa_alt(secure_config->pkey_alt_ctx,
                                          (void *)mbedtls_pk_rsa(*secure_config->pkey_ctx),
                                           tls_server_dpm_sample_rsa_decrypt_func,
                                           tls_server_dpm_sample_rsa_sign_func,
                                           tls_server_dpm_sample_rsa_key_len_func);
```


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```
        ret = mbedtls_ssl_conf_own_cert(secure_config->ssl_conf,
                                        secure_config->cert_crt,
                                        secure_config->pkey_alt_ctx);
    } else {
        ret = mbedtls_ssl_conf_own_cert(secure_config->ssl_conf,
                                        secure_config->cert_crt,
                                        secure_config->pkey_ctx);
    }

    ret = dpm_mng_setup_rng(secure_config->ssl_conf);

    //Don't care verification in this sample.
    mbedtls_ssl_conf_authmode(secure_config->ssl_conf, MBEDTLS_SSL_VERIFY_NONE);

    ret = mbedtls_ssl_setup(secure_config->ssl_ctx, secure_config->ssl_conf);

    dpm_mng_job_done(); //Done opertaion

    return ;
}
```

10.3.3.3 Data Transmission

The callback function is called when a TLS packet is received from a TLS client. In this sample, the received data is printed out and an echo message is sent to the TLS server. Data is encrypted and decrypted in the callback function.

```
void tls_server_dpm_sample_recv_callback(void *sock, UCHAR *rx_buf, UINT rx_len,
                                         ULONG rx_ip, ULONG rx_port)
{
    //Display received packet
    PRINTF(" =====> Received Packet(%ld) \n", rx_len);

    //Echo message
    status = dpm_mng_send_to_session(SESSION1, rx_ip, rx_port, (char *)rx_buf,
                                     rx_len);

    if (status) {
        PRINTF(RED_COLOR " [%s] Fail send data(session%d,0x%x) \n" CLEAR_COLOR,
               __func__, SESSION1, status);
    } else {
        //Display sent packet
        PRINTF(" <===== Sent Packet(%ld) \n", rx_len);
    }

    dpm_mng_job_done(); //Done opertaion
}
```

10.4 TLS Client

This section describes how the TLS client sample application is built and works. The TLS client sample application is an example of the simplest TLS echo client application. TLS is cryptographic protocols designed to provide secured communication over a computer network. The DA16200 SDK provides a DPM manager for the user network application. The DA16200 SDK provides an SSL library called “mbedTLS” on a secure H/W engine to support the TLS protocol. “MbedTLS” is one of the popular SSL libraries and helps to easily develop a network application with a TLS protocol.

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10.4.1 How to Run

1. Run a TLS server application on the peer PC and open a TLS server socket with port number 10196.
2. In the e²studio, import a project for the TLS Client sample application as follows:
   - *~/SDK/apps/common/examples/Network/TLS_Client/projects/da16200*
3. Build the DA16200 SDK, download the RTOS image to the DA16200 EVB, and reboot.
4. Use the console command to set up the Wi-Fi station interface.
5. After a connection is made to an AP, the example application connects to the peer.

10.4.2 How It Works

The DA16200 TLS Client sample is a simple echo message. When the TLS server sends a message, then the DA16200 TLS client echoes that message to the TLS server.

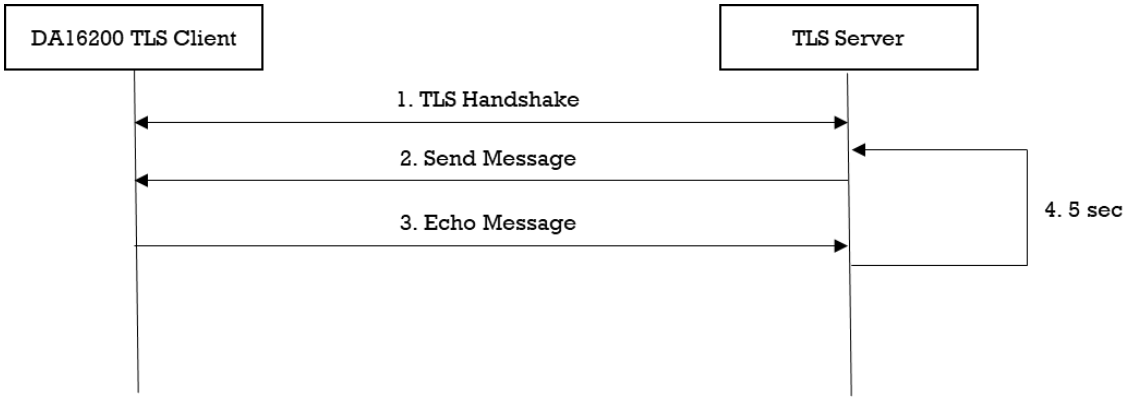

Figure 33: Workflow of TLS Client

10.4.3 Sample Code

DA16200 SDK provides the “mbedTLS” library. It describes how the TLS client is implemented with the “mbedTLS” library and socket library.

10.4.3.1 Registration

The DA16200 secure H/W engine has to be initialized with da16x_secure_module_init() before the TLS context is initialized. To set up a TLS session, initialization functions are called as follows:

```
void tls_client_sample(void *param)
{
      ...

      //Init session
      mbedtls_net_init(&server_ctx);

      //Init SSL context
      mbedtls_ssl_init(&ssl_ctx);

      //Init SSL config
      mbedtls_ssl_config_init(&ssl_conf);

      //Init CTR-DRBG context
      mbedtls_ctr_drbg_init(&ctr_drbg);

      //Init Entropy context
      mbedtls_entropy_init(&entropy);
```


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```
    snprintf(str_port, sizeof(str_port), "%d", TLS_CLIENT_SAMPLE_DEF_SERVER_PORT);
    ret = mbedtls_net_connect(&server_ctx,
                              TLS_CLIENT_SAMPLE_DEF_SERVER_IP_ADDR, str_port,
                              MBEDTLS_NET_PROTO_TCP);

    //Set default configuration
    ret = mbedtls_ssl_config_defaults(&ssl_conf,
                                      MBEDTLS_SSL_IS_CLIENT,
                                      MBEDTLS_SSL_TRANSPORT_STREAM,
                                      MBEDTLS_SSL_PRESET_DEFAULT);

    ret = mbedtls_ctr_drbg_seed(&ctr_drbg, mbedtls_entropy_func, &entropy,
                                (const unsigned char *)pers, strlen(pers));

    mbedtls_ssl_conf_rng(&ssl_conf, mbedtls_ctr_drbg_random, &ctr_drbg);

    //Don't care verification in this sample.
    mbedtls_ssl_conf_authmode(&ssl_conf, MBEDTLS_SSL_VERIFY_NONE);

    //Setup an SSL context for use.
    ret = mbedtls_ssl_setup(&ssl_ctx, &ssl_conf);

    mbedtls_ssl_set_bio(&ssl_ctx, &server_ctx,
                                mbedtls_net_send, mbedtls_net_recv, NULL);

    ...
}
```

10.4.3.2 TLS Handshake

TLS is an encryption protocol designed to secure network communication. A TLS handshake is the process that starts a communication session that uses TLS encryption. To do a TLS handshake, function mbedtls_ssl_handshake() is called. If an error occurred during the TLS handshake, the API returns a specific error code. If a TLS session is established successfully, the API returns 0. The details are as follows:

```
void tls_client_sample(void *param)
{
    ...
reset:
    ...
    while ((ret = mbedtls_ssl_handshake(&ssl_ctx)) != 0) {
       if (ret == MBEDTLS_ERR_NET_CONN_RESET) {
            PRINTF("\r\n[%s] Peer closed the connection(0x%x)\r\n", __func__, -ret);
            goto end_of_task;
       }

       if ((ret != MBEDTLS_ERR_SSL_WANT_READ) &&
                                      (ret != MBEDTLS_ERR_SSL_WANT_WRITE)) {
            PRINTF("\r\n[%s] Failed to do tls handshake(0x%x)\r\n", __func__, -ret);
            goto end_of_task;
       }
    }
    ...
 }
```

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10.4.3.3 Data Transmission

Encryption scrambles data so that only authorized parties can understand the information. While a TLS session is established, all data must be encrypted to transfer application data. “MbedTLS” provides specific APIs to help encrypt and decrypt data. To write application data, function mbedtls_ssl_write() of the “mbedTLS” library is called. The details are as follows:

```
void tls_client_sample(void *param)
{
    ...
    do {
        ...
        while ((ret = mbedtls_ssl_write(&ssl_ctx, data_buffer, len)) <= 0) {
            switch (ret) {
                case MBEDTLS_ERR_SSL_WANT_READ:
                case MBEDTLS_ERR_SSL_WANT_WRITE:
                    PRINTF("\r\nNeed more data - mbedtls_ssl_write(0x%x)\r\n", -ret);
                    continue;
                case MBEDTLS_ERR_SSL_PEER_CLOSE_NOTIFY:
                    PRINTF("\r\nConnection was closed gracefully\r\n");
                    break;
                case MBEDTLS_ERR_NET_CONN_RESET:
                    PRINTF("\r\nConnection was reset by peer\r\n");
                    break;
                default:
                    PRINTF("\r\nFailed to write data(0x%x)\r\n", -ret);
                    break;
            }
            goto end_of_task;
        }
    }
    ...
}
```

To read application data, function mbedtls_ssl_read() of the “mbedTLS” library is called. In this sample, this function is called in tls_client_sample(). The details are as follows:

```
void tls_client_sample(void *param)
{
    ...
    do {
        len = sizeof(data_buffer) - 1;
        memset(data_buffer, 0x00, sizeof(data_buffer));

        PRINTF("< Read from server: ");

        //Read at most 'len' application data bytes.
        ret = mbedtls_ssl_read(&ssl_ctx, data_buffer, len);
        if (ret <= 0) {
            switch (ret) {
                case MBEDTLS_ERR_SSL_WANT_READ:
                case MBEDTLS_ERR_SSL_WANT_WRITE:
                    PRINTF("\r\nNeed more data - mbedtls_ssl_read(0x%x)\r\n", -ret);
                    continue;
                case MBEDTLS_ERR_SSL_PEER_CLOSE_NOTIFY:
                    PRINTF("\r\nConnection was closed gracefully\r\n");
                    goto end_of_task;
                case MBEDTLS_ERR_NET_CONN_RESET:
                    PRINTF("\r\nConnection was reset by peer\r\n");
                    goto end_of_task;
                default:
```

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```
                    PRINTF("\r\nFailed to read data(0x%x)\r\n", -ret);
                    break;
            }
            goto end_of_task;
        }

        len = ret;
        PRINTF("%d bytes read\r\n", len);

        while ((ret = mbedtls_ssl_write(&ssl_ctx, data_buffer, len)) <= 0) {
            ...
        }
    }
    ...
}
```

10.5 TLS Client in DPM

This section describes how the TLS client in the DPM sample application is built and works. The TLS client in the DPM sample application is an example of the simplest TLS echo client application in DPM mode. TLS is a set of cryptographic protocols designed to provide secured communication over a computer network. The DA16200 SDK can work in DPM mode. The user application requires an additional operation to work in DPM mode. The DA16200 SDK provides a DPM manager for the user network application. The DPM manager supports the user to develop and manage the TLS network application in Non-DPM and DPM modes.

10.5.1 How to Run

1. Run a TLS server application on the peer PC and open a TLS server socket with port number 10196.
2. In the e^{2}studio, import a project for a TCP Client in the DPM sample application as follows:
   - *~/SDK/apps/common/examples/Network/TLS_Client_DPM/projects/da16200*
3. Build the DA16200 SDK, download the RTOS image to the DA16200 EVB, and reboot.
4. Use the console command to set up the Wi-Fi station interface.
5. Set the TLS server IP address and the port number as created the socket on the peer PC with the following console command and then reboot. These parameters can also be defined in the source code.

   [/DA16200] # nvram.setenv TLSC_SERVER_IP 192.168.0.11
   [/DA16200] # nvram.setenv TLSC_SERVER_PORT 10196
   [/DA16200] # reboot

After connecting to the AP, the example application connects to the peer PC.

10.5.2 How It Works

The DA16200 TLS Client in the DPM sample is a simple echo message. When a TLS server sends a message, then the DA16200 TLS client echoes that message to the TLS server.

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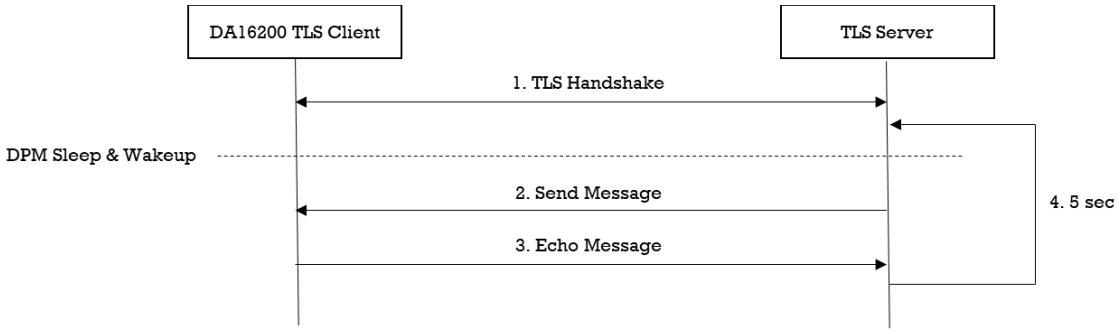

Figure 34: Workflow of TLS Client in DPM

10.5.3 Sample Code

10.5.3.1 Registration

The TLS client in the DPM sample application works in DPM mode. The basic code is similar to the TLS client sample application. There are two differences with the TLS client sample application:

- An initial callback function is added, named tls_client_dpm_sample_wakeup_callback() in the code. It will be called when the DPM state changes from sleep to wake-up
- Additional user configuration that can be stored in RTM

In this example, TLS server information is stored.

```
void tls_client_dpm_sample_init_user_config(dpm_user_config_t *user_config)
{
      const int session_idx = 0;

      //Set Boot init callback
      user_config->bootInitCallback = tls_client_dpm_sample_init_callback;

      //Set DPM wakeup init callback
      user_config->wakeupInitCallback = tls_client_dpm_sample_wakeup_callback;

      //Set External wakeup callback
      user_config->externWakeupCallback = tls_client_dpm_sample_external_callback;

      //Set Error callback
      user_config->errorCallback = tls_client_dpm_sample_error_callback;

      //Set session type(TLS Client)
      user_config->sessionConfig[session_idx].sessionType = REG_TYPE_TCP_CLIENT;

      //Set local port
      user_config->sessionConfig[session_idx].sessionMyPort =
       TLS_CLIENT_DPM_SAMPLE_DEF_CLIENT_PORT;

      //Set server IP address
      memcpy(user_config->sessionConfig[session_idx].sessionServerIp,
          srv_info.ip_addr, strlen(srv_info.ip_addr));

      //Set server port
      user_config->sessionConfig[session_idx].sessionServerPort = srv_info.port;

      //Set Connection callback
      user_config->sessionConfig[session_idx].sessionConnectCallback =
       tls_client_dpm_sample_connect_callback;

      //Set Recv callback
```


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```
        user_config->sessionConfig[session_idx].sessionRecvCallback =
         tls_client_dpm_sample_recv_callback;

        //Set connection retry count
        user_config->sessionConfig[session_idx].sessionConnRetryCnt =
         TLS_CLIENT_DPM_SAMPLE_DEF_MAX_CONNECTION_RETRY;

        //Set connection timeout
        user_config->sessionConfig[session_idx].sessionConnWaitTime =
         TLS_CLIENT_DPM_SAMPLE_DEF_MAX_CONNECTION_TIMEOUT;

        //Set auto reconnection flag
        user_config->sessionConfig[session_idx].sessionAutoReconn = pdTRUE;

        //Set secure mode
        user_config->sessionConfig[session_idx].supportSecure = pdTRUE;

        //Set secure setup callback
        user_config->sessionConfig[session_idx].sessionSetupSecureCallback =
         tls_client_dpm_sample_secure_callback;

        //Set user configuration
        user_config->ptrDataFromRetentionMemory = (UCHAR *)&srv_info;
        user_config->sizeOfRetentionMemory = sizeof(tls_client_dpm_sample_svr_info_t);

        return ;
}
```

10.5.3.2 TLS Setup

To establish a TLS session, TLS should be set up. DA16200 includes the “mbedTLS” library to provide the TLS protocol. Most APIs that are related to the TLS protocol are based on an “mbedTLS” library. TLS is set up by sessionSetupSecureCallback function. The details are as shown below. Note that this sample application does not include certificates.

```
void tls_client_dpm_sample_secure_callback(void *config)
{
        const char *pers = "tls_client_sample";
        SECURE_INFO_T *secure_config = (SECURE_INFO_T *)config;

        ret = mbedtls_ssl_config_defaults(secure_config->ssl_conf,
                                          MBEDTLS_SSL_IS_CLIENT,
                                          MBEDTLS_SSL_TRANSPORT_STREAM,
                                          MBEDTLS_SSL_PRESET_DEFAULT);

        ret = dpm_mng_setup_rng(secure_config->ssl_conf);

        //Don't care verification in this sample.
        mbedtls_ssl_conf_authmode(secure_config->ssl_conf, MBEDTLS_SSL_VERIFY_NONE);

        ret = mbedtls_ssl_setup(secure_config->ssl_ctx, secure_config->ssl_conf);

        dpm_mng_job_done(); //Done opertaion
        return ;
}
```

10.5.3.3 Data Transmission

The callback function is called when the TLS packet is received from the TLS server. In this sample, the received data is printed out and an echo message is sent to the TLS server. Data is encrypted and decrypted in the callback function.

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```
void tls_client_dpm_sample_recv_callback(void *sock, UCHAR *rx_buf, UINT rx_len,
                                         ULONG rx_ip, ULONG rx_port)
{
      //Display received packet
      PRINTF(" =====> Received Packet(%ld) \n", rx_len);

      status = dpm_mng_send_to_session(SESSION1, rx_ip, rx_port, (char *)rx_buf,
                                       rx_len);
      if (status)
      {
            PRINTF(RED_COLOR " [%s] Fail send data(session%d,0x%x) \n" CLEAR_COLOR,
                   __func__, SESSION1, status);
      }
      else
      {
            //Display sent packet
            PRINTF(" <===== Sent Packet(%ld) \n", rx_len);
      }

      dpm_mng_job_done(); //Done opertaion}
```

10.6 DTLS Server

This section describes how the Datagram Transport Layer Security (DTLS) server sample application is built and works. The DTLS server sample application is an example of the simplest DTLS echo server application. DTLS is a cryptographic protocol that provides security for datagram-based applications by allowing them to communicate in a way that is designed to prevent eavesdropping, tampering, or message forgery. The DA16200 SDK provides an SSL library called “mbedTLS” on a secure H/W engine to support the DTLS protocol. “mbedTLS” is one of the popular SSL libraries. “mbedTLS” is helpful to develop a network application with a DTLS protocol.

10.6.1 How to Run

1. In the e^{2}studio, import a project for the DTLS Server sample application as follows:
   - *~/SDK/apps/common/examples/Network/DTLS_Server/projects/da16200*
2. Build the DA16200 SDK, download the RTOS image to the DA16200 EVB, and reboot.
3. Use the console command to set up the Wi-Fi station interface.
4. After a connection is made to an AP, the example application creates a DTLS server socket with port number 10199 and waits for a client connection.
5. Run a DTLS client application on the peer PC.

10.6.2 How It Works

The DA16200 DTLS Server sample is a simple echo server. When the DTLS client sends a message, then the DA16200 DTLS server echoes that message to the DTLS client.

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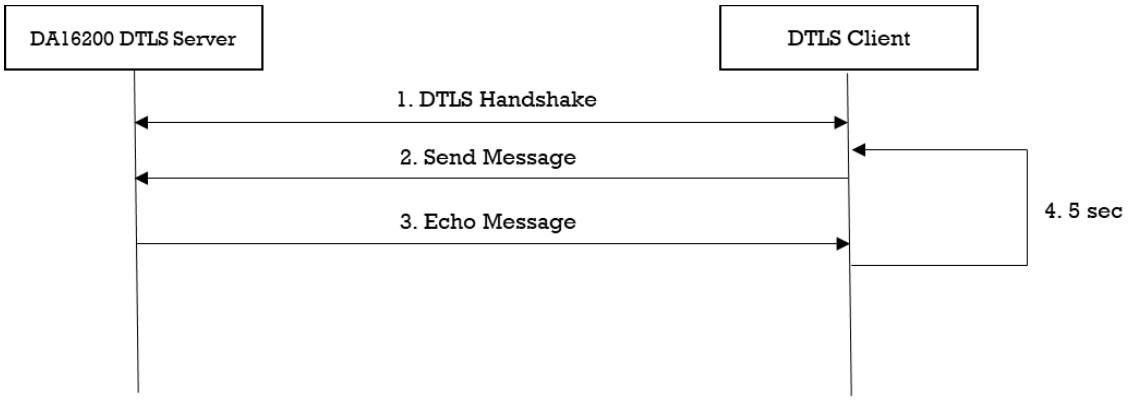

Figure 35: Workflow of DTLS Server

10.6.3 Sample Code

The DA16200 SDK provides the “mbedTLS” library. This sample application describes how the “mbedTLS” library is called and applied for the socket library.

10.6.3.1 Initialization

The DA16200 secure H/W engine has to be initialized with da16x_secure_module_init() before the TLS context is initialized. To set up a DTLS session, initialization functions are called as shown in the example code below. The DTLS session is established over a UDP protocol. In case a packet is lost, retransmission is required. So, the timer is registered to retransmit packet by function mbedtls_ssl_set_timer_cb().

```
void dtls_server_sample(void *param)
{
    ...

    //Init session
    mbedtls_net_init(&listen_ctx);
    mbedtls_net_init(&client_ctx);

    //Init SSL context
    mbedtls_ssl_init(&ssl_ctx);

    //Init SSL config
    mbedtls_ssl_config_init(&ssl_conf);

    //Init CTR-DRBG context
    mbedtls_ctr_drbg_init(&ctr_drbg);

    //Init Entropy context
    mbedtls_entropy_init(&entropy);

    //Init Certificate context
    mbedtls_x509_crt_init(&cert);

    //Init Private key context
    mbedtls_pk_init(&pkey);

    //Init Private key context for ALT
    mbedtls_pk_init(&pkey_alt);

    //Init Cookies
    mbedtls_ssl_cookie_init(&cookies);
    memset(&timer, 0x00, sizeof(dtls_server_sample_timer_t));
```


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```
//Parse certificate
ret = mbedtls_x509_crt_parse(&cert, dtls_server_sample_cert,
                             dtls_server_sample_cert_len);
//Parse private key
ret = mbedtls_pk_parse_key(&pkey, dtls_server_sample_key,
                           dtls_server_sample_key_len, NULL, 0);

snprintf(str_port, sizeof(str_port), "%d", DTLS_SERVER_SAMPLE_DEF_PORT);

ret = mbedtls_net_bind(&listen_ctx, NULL, str_port, MBEDTLS_NET_PROTO_UDP);
ret = mbedtls_ctr_drbg_seed(&ctr_drbg, mbedtls_entropy_func, &entropy,
                            (const unsigned char *)pers, strlen(pers));

//Set default configuration
ret = mbedtls_ssl_config_defaults(&ssl_conf,
                                  MBEDTLS_SSL_IS_SERVER,
                                  MBEDTLS_SSL_TRANSPORT_DATAGRAM,
                                  MBEDTLS_SSL_PRESET_DEFAULT);

mbedtls_ssl_conf_rng(&ssl_conf, mbedtls_ctr_drbg_random, &ctr_drbg);

//Import certificate & private key
if (mbedtls_pk_get_type(&pkey) == MBEDTLS_PK_RSA) {
    ret = mbedtls_pk_setup_rsa_alt(&pkey_alt,
                                   (void *)mbedtls_pk_rsa(pkey),
                                   dtls_server_sample_rsa_decrypt_func,
                                   dtls_server_sample_rsa_sign_func,
                                   dtls_server_sample_rsa_key_len_func);

    ret = mbedtls_ssl_conf_own_cert(&ssl_conf, &cert, &pkey_alt);
} else {
    ret = mbedtls_ssl_conf_own_cert(&ssl_conf, &cert, &pkey);
}

//Setup cookies
ret = mbedtls_ssl_cookie_setup(&cookies, mbedtls_ctr_drbg_random, &ctr_drbg);

//Register callbacks for DTLS cookies.
mbedtls_ssl_conf_dtls_cookies(&ssl_conf,
                              mbedtls_ssl_cookie_write,
                              mbedtls_ssl_cookie_check,
                              &cookies);

//Don't care verificate of peer certificate
mbedtls_ssl_conf_authmode(&ssl_conf, MBEDTLS_SSL_VERIFY_NONE);

//Enable or disable anti-replay protection for DTLS.
mbedtls_ssl_conf_dtls_anti_replay(&ssl_conf, MBEDTLS_SSL_ANTI_REPLAY_ENABLED);
mbedtls_ssl_conf_read_timeout(&ssl_conf, DTLS_SERVER_SAMPLE_DEF_TIMEOUT);

//Set retransmit timeout values for the DTLS handshake.
mbedtls_ssl_conf_handshake_timeout(&ssl_conf,
                                   DTLS_SERVER_SAMPLE_DEF_HANDSHAKE_MIN_TIMEOUT,
                                   DTLS_SERVER_SAMPLE_DEF_HANDSHAKE_MAX_TIMEOUT);

//Set up an SSL context for use.
ret = mbedtls_ssl_setup(&ssl_ctx, &ssl_conf);
mbedtls_ssl_set_timer_cb(&ssl_ctx, &timer, dtls_server_sample_timer_start,
                         dtls_server_sample_timer_get_state);
```

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```
reset:
     ...
     ret = mbedtls_ssl_set_client_transport_id(&ssl_ctx, client_ip, client_ip_len);
     mbedtls_ssl_set_bio(&ssl_ctx, &client_ctx, mbedtls_net_send, NULL,
                         mbedtls_net_recv_timeout);
     ...
}
```

10.6.3.2 DTLS Handshake

DTLS is an encryption protocol designed to secure network communication. A DTLS handshake is the process that starts a communication session with DTLS encryption. To do a DTLS handshake, the application calls function mbedtls_ssl_handshake(). The DTLS server must verify cookies for the DTLS client. The DTLS client's transport-level identification information must be set up (generally an IP Address). After a ClientHello message is received, the DTLS server must set up its IP address. Then, a DTLS handshake should be retried as follows:

```
void dtls_server_sample(void *param)
{
    ...
reset:
    ...
    while ((ret = mbedtls_ssl_handshake(&ssl_ctx)) != 0) {
        if ((ret == MBEDTLS_ERR_SSL_WANT_READ) ||
                                        (ret == MBEDTLS_ERR_SSL_WANT_WRITE)) {
            continue;
        }
        if (ret == MBEDTLS_ERR_SSL_HELLO_VERIFY_REQUIRED) {
            PRINTF("hello verification requested\r\n");
            ret = 0;
            goto reset;
        } else {
            PRINTF("\r\n[%s] Failed to do handshake(0x%x)\r\n", __func__, -ret);
            goto reset;
        }
    }
    ...
 }
```

10.6.3.3 Data Transmission

Encryption scrambles data so that only authorized parties can understand the information. While a DTLS session is established, all data must be encrypted for transfer. “mbedTLS” provides specific APIs to help encrypt and decrypt data. To write application data, function mbedtls_ssl_write() of the “mbedTLS” library is called. The details are as follows:

```
void dtls_server_sample(void *param){
    ...
    do {
        ...
        while ((ret = mbedtls_ssl_write(&ssl_ctx, data_buffer, len)) <= 0) {
            switch (ret) {
                case MBEDTLS_ERR_SSL_WANT_READ:
                case MBEDTLS_ERR_SSL_WANT_WRITE:
                    PRINTF("\r\nNeed more data - mbedtls_ssl_write(0x%x)\r\n", -ret);
                    continue;
            }
            PRINTF("\r\n[%s] Failed to write data(0x%x)\r\n", __func__, -ret);
            goto end_of_task;
        }
        PRINTF("%d bytes written\r\n", len);
    }
```

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```
    ...
}
```

To read application data, function mbedtls_ssl_read() of the “mbedTLS” library is called. In this sample, this function is called in dtls_server_sample(). The details are as follows:

```
void dtls_server_sample(void *param){
    ...
    do {
        len = sizeof(data_buffer) - 1;
        memset(data_buffer, 0x00, sizeof(data_buffer));

        PRINTF("< Read from server: ");

        //Read at most 'len' application data bytes.
        ret = mbedtls_ssl_read(&ssl_ctx, data_buffer, len);
        if (ret <= 0) {
            switch (ret) {
                case MBEDTLS_ERR_SSL_WANT_READ:
                case MBEDTLS_ERR_SSL_WANT_WRITE:
                    PRINTF("\r\nNeed more data - mbedtls_ssl_write(0x%x)\r\n", -ret);
                    continue;
                case MBEDTLS_ERR_SSL_PEER_CLOSE_NOTIFY:
                    PRINTF("\r\nConnection was closed gracefully\r\n");
                    ret = 0;
                    goto close_notify;
                case MBEDTLS_ERR_SSL_TIMEOUT:
                    PRINTF("\r\nTimeout\r\n");
                    goto reset;
                default:
                    PRINTF("\r\nFailed to read data(0x%x)\r\n", -ret);
                    break;
            }
            goto reset;
        }

        len = ret;
        PRINTF("%d bytes read\r\n", len);

        PRINTF("> Write to client: ");
        while ((ret = mbedtls_ssl_write(&ssl_ctx, data_buffer, len)) <= 0) {      ...
        }
    }
    ...
}
```

10.7 DTLS Server in DPM

This section describes how the DTLS server in the DPM sample application is built and works. The DTLS server in the DPM sample application is an example of the simplest DTLS echo server application. DTLS is a cryptographic protocol that provides security for datagram-based applications by allowing them to communicate in a way that is designed to prevent eavesdropping, tampering, or message forgery. The DA16200 SDK can work in DPM mode. The user application requires an additional operation to work in DPM mode. The DA16200 SDK provides a DPM manager for the user network application. The DPM manager supports the user to develop and manage a DTLS network application in Non-DPM and DPM modes.

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10.7.1 How to Run

1. In the e²studio, import a project for the DTLS Server in the DPM sample application as follows:
   - *~/SDK/apps/common/examples/Network/DTLS_Server_DPM/projects/da16200*
2. Build the DA16200 SDK, download the RTOS image to the DA16200 EVB, and reboot.
3. Use the console command to set up the Wi-Fi station interface.
4. After a connection is made to an AP, the example application creates a DTLS server socket with port number 10199 and waits for a client connection.
5. Run a DTLS client application on the peer PC.

10.7.2 How It Works

The DA16200 DTLS Server in the DPM sample is a simple echo server. When a DTLS client sends a message, then the DA16200 DTLS server echoes that message to the DTLS client.

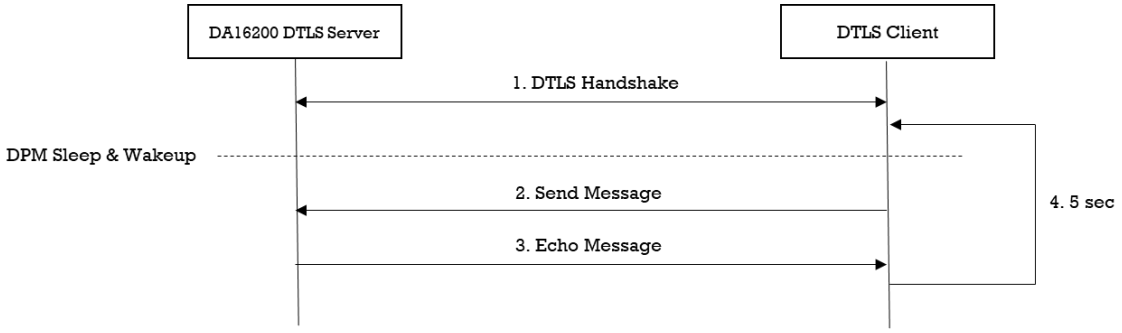

Figure 36: Workflow of DTLS Server in DPM

10.7.3 Sample Code

10.7.3.1 Registration

The DTLS server in the DPM sample application works in DPM mode. The basic code is similar to the DTLS server sample application. There are two differences with the DTLS server sample application:

- An initial callback function is added, named dtls_server_dpm_sample_wakeup_callback() in the code. It is called when the DPM state changes from sleep to wake-up
- Additional user configuration can be stored in RTM

In this sample, DTLS server information is stored.

```
void dtls_server_dpm_sample_init_user_config(dpm_user_config_t *user_config)
{
      const int session_idx = 0;

      //Set Boot init callback
      user_config->bootInitCallback = dtls_server_dpm_sample_init_callback;

      //Set DPM wakkup init callback
      user_config->wakeupInitCallback = dtls_server_dpm_sample_wakeup_callback;

      //Set Error callback
      user_config->errorCallback = dtls_server_dpm_sample_error_callback;

      //Set session type(UDP Server)
      user_config->sessionConfig[session_idx].sessionType = REG_TYPE_UDP_SERVER;

      //Set local port
      user_config->sessionConfig[session_idx].sessionMyPort =
```


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```
 DTLS_SERVER_DPM_SAMPLE_DEF_SERVER_PORT;

//Set Connection callback
user_config->sessionConfig[session_idx].sessionConnectCallback =
 dtls_server_dpm_sample_connect_callback;

//Set Recv callback
user_config->sessionConfig[session_idx].sessionRecvCallback =
 dtls_server_dpm_sample_recv_callback;

//Set secure mode
user_config->sessionConfig[session_idx].supportSecure = pdTRUE;

//Set secure setup callback
user_config->sessionConfig[session_idx].sessionSetupSecureCallback =
 dtls_server_dpm_sample_secure_callback;

//Set user configuration
user_config->ptrDataFromRetentionMemory = (UCHAR *)&srv_info;
user_config->sizeOfRetentionMemory =
  sizeof(dtls_server_dpm_sample_svr_info_t);

return ; }
```

10.7.3.2 DTLS Setup

To establish a DTLS session, DTLS should be set up. The DA16200 includes an “mbedTLS” library to provide the DTLS protocol. Most APIs that are related to the DTLS protocol are based on an “mbedTLS” library. DTLS is set up by sessionSetupSecureCallback function. The details are as follows.

```
void dtls_server_dpm_sample_secure_callback(void *config)
{
      const char *pers = "dtls_server_dpm_sample";
      SECURE_INFO_T *secure_config = (SECURE_INFO_T *)config;

      ret = mbedtls_ssl_config_defaults(secure_config->ssl_conf,
                                        MBEDTLS_SSL_IS_SERVER,
                                        MBEDTLS_SSL_TRANSPORT_DATAGRAM,
                                        MBEDTLS_SSL_PRESET_DEFAULT);

      //import test certificate
      ret = mbedtls_x509_crt_parse(secure_config->cert_crt,
                                   dtls_server_dpm_sample_cert,
                                   dtls_server_dpm_sample_cert_len);

      ret = mbedtls_pk_parse_key(secure_config->pkey_ctx,
                                 dtls_server_dpm_sample_key,
                                 dtls_server_dpm_sample_key_len,
                                 NULL, 0);

      if (mbedtls_pk_get_type(secure_config->pkey_ctx) == MBEDTLS_PK_RSA) {
          ret = mbedtls_pk_setup_rsa_alt(secure_config->pkey_alt_ctx,
                                   (void *)mbedtls_pk_rsa(*secure_config->pkey_ctx),
                                   dtls_server_dpm_sample_rsa_decrypt_func,
                                   dtls_server_dpm_sample_rsa_sign_func,
                                   dtls_server_dpm_sample_rsa_key_len_func);


          ret = mbedtls_ssl_conf_own_cert(secure_config->ssl_conf,
                                          secure_config->cert_crt,
```

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```
                                        secure_config->pkey_alt_ctx);
        } else {
            ret = mbedtls_ssl_conf_own_cert(secure_config->ssl_conf,
                                        secure_config->cert_crt,
                                        secure_config->pkey_ctx);
        }

        ret = dpm_mng_setup_rng(secure_config->ssl_conf);
        ret = dpm_mng_cookie_setup_rng(secure_config->cookie_ctx);
        mbedtls_ssl_conf_dtls_cookies(secure_config->ssl_conf,
                                    mbedtls_ssl_cookie_write,
                                    mbedtls_ssl_cookie_check,
                                    secure_config->cookie_ctx);

        //Don't care verification in this sample.
        mbedtls_ssl_conf_authmode(secure_config->ssl_conf, MBEDTLS_SSL_VERIFY_NONE);

        //use default value
        mbedtls_ssl_conf_max_frag_len(secure_config->ssl_conf, 0);
        mbedtls_ssl_conf_dtls_anti_replay(secure_config->ssl_conf,
                                        MBEDTLS_SSL_ANTI_REPLAY_ENABLED);

        mbedtls_ssl_conf_read_timeout(secure_config->ssl_conf,
                                    DTLS_SERVER_DPM_SAMPLE_RECEIVE_TIMEOUT * 10);

        mbedtls_ssl_conf_handshake_timeout(secure_config->ssl_conf,
                                DTLS_SERVER_DPM_SAMPLE_HANDSAHKE_MIN_TIMEOUT * 10,
                                DTLS_SERVER_DPM_SAMPLE_HANDSAHKE_MAX_TIMEOUT * 10);

        ret = mbedtls_ssl_setup(secure_config->ssl_ctx, secure_config->ssl_conf);

        dpm_mng_job_done(); //Done opertaion
        return ;
}
```

10.7.3.3 Data Transmission

The callback function is called when a DTLS packet is received from the DTLS client. In this example, the received data is printed out and an echo message is sent to the DTLS server. Data is encrypted and decrypted in the callback function.

```
void dtls_server_dpm_sample_recv_callback(void *sock, UCHAR *rx_buf, UINT rx_len,
                                        ULONG rx_ip, ULONG rx_port)
{
        //Display received packet
        PRINTF(" ==> Received Packet(%ld) \n", rx_len);

        //Echo message
        status = dpm_mng_send_to_session(SESSION1,
                                    rx_ip,
                                    rx_port,
                                    (char *)rx_buf,
                                    rx_len);


        if (status) {
            PRINTF(RED_COLOR " [%s] Fail send data(session%d,0x%x) \n" CLEAR_COLOR,
                    __func__, SESSION1, status);
        } else {
            //Display sent packet
            PRINTF(" <== Sent Packet(%ld) \n", rx_len);
```

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```
}

dpm_mng_job_done(); //Done opertaion}
```

10.8 DTLS Client

This section describes how the DTLS client sample application is built and works. The DTLS client sample application is an example of the simplest DTLS echo client application. DTLS is a cryptographic protocol that provides security for datagram-based applications by allowing them to communicate in a way that is designed to prevent eavesdropping, tampering, or message forgery. The DA16200 SDK provides an SSL library called “mbedTLS” on a secure H/W engine to support the DTLS protocol. “mbedTLS” is one of the popular SSL libraries. “mbedTLS” is helpful to easily develop a network application with the DTLS protocol.

10.8.1 How to Run

1. Run a DTLS server application on the peer PC and open a DTLS server socket with port number 10199.
2. In the e²studio, import a project for the DTLS Client sample application as follows:
   - *~/SDK/apps/common/examples/Network/DTLS_Client/projects/da16200*
3. Build the DA16200 SDK, download the RTOS image to the DA16200 EVB, and reboot.
4. Use the console command to set up the Wi-Fi station interface.

After a connection is made to an AP, the sample application connects to the peer PC.

10.8.2 How It Works

The DA16200 DTLS Client sample is a simple echo message. When the DTLS server sends a message, then the DA16200 DTLS client echoes that message to the DTLS server.

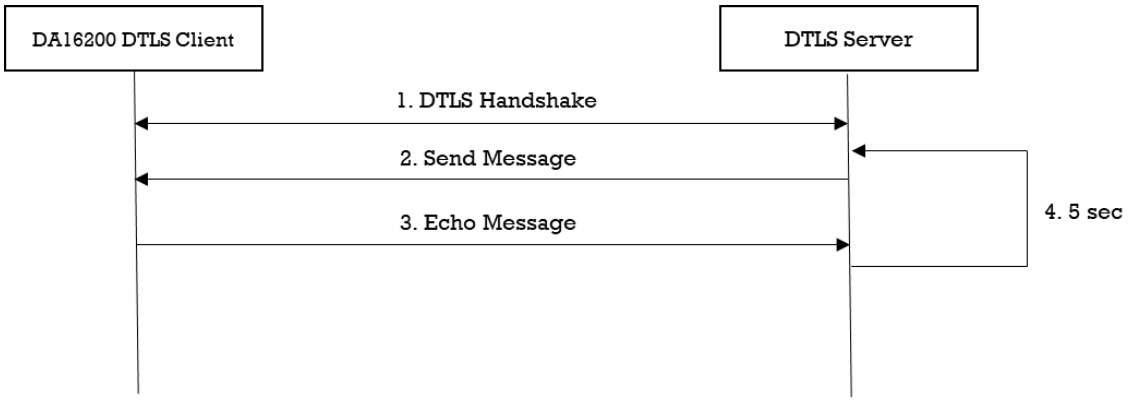

Figure 37: Workflow of DTLS Client

10.8.3 Sample Code

The DA16200 SDK provides an “mbedTLS” library. This sample application describes how an “mbedTLS” library is called and applied for the socket library.

10.8.3.1 Initialization

The DA16200 secure H/W engine has to be initialized with da16x_secure_module_init() before the DTLS context is initialized. To set up a DTLS session, initialization functions are called as shown in the example code below. A DTLS session is established over the UDP protocol. If a packet is lost, then retransmission is required. So, the timer is registered to retransmit the packet by function mbedtls_ssl_set_timer_cb().

```
void dtls_client_sample(void *param)
{
```


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```
    ...

    //Init session
    mbedtls_net_init(&server_ctx);

    //Init SSL context
    mbedtls_ssl_init(&ssl_ctx);

    //Init SSL config
    mbedtls_ssl_config_init(&ssl_conf);

    //Init CTR-DRBG context
    mbedtls_ctr_drbg_init(&ctr_drbg);

    //Init Entropy context
    mbedtls_entropy_init(&entropy);

    memset(&timer, 0x00, sizeof(dtls_client_sample_timer_t));

    PRINTF("\r\nConnecting to udp/%s:%d...",
           DTLS_CLIENT_SAMPLE_DEF_SERVER_IP_ADDR,
           DTLS_CLIENT_SAMPLE_DEF_SERVER_PORT);

    snprintf(str_port, sizeof(str_port),"%d", DTLS_CLIENT_SAMPLE_DEF_SERVER_PORT);

    ret = mbedtls_net_connect(&server_ctx,
                              DTLS_CLIENT_SAMPLE_DEF_SERVER_IP_ADDR, str_port,
                              MBEDTLS_NET_PROTO_UDP);

    ret = mbedtls_ssl_config_defaults(&ssl_conf,
                                      MBEDTLS_SSL_IS_CLIENT,
                                      MBEDTLS_SSL_TRANSPORT_DATAGRAM,
                                      MBEDTLS_SSL_PRESET_DEFAULT);

    ret = mbedtls_ctr_drbg_seed(&ctr_drbg, mbedtls_entropy_func, &entropy,
                                (const unsigned char *)pers, strlen(pers));

    mbedtls_ssl_conf_rng(&ssl_conf, mbedtls_ctr_drbg_random, &ctr_drbg);
    mbedtls_ssl_conf_authmode(&ssl_conf, MBEDTLS_SSL_VERIFY_NONE);
    mbedtls_ssl_conf_dtls_anti_replay(&ssl_conf, MBEDTLS_SSL_ANTI_REPLAY_ENABLED);
    mbedtls_ssl_conf_read_timeout(&ssl_conf, DTLS_CLIENT_SAMPLE_DEF_TIMEOUT);
    mbedtls_ssl_conf_handshake_timeout(&ssl_conf,
                                       DTLS_CLIENT_SAMPLE_DEF_HANDSHAKE_MIN_TIMEOUT,
                                       DTLS_CLIENT_SAMPLE_DEF_HANDSHAKE_MAX_TIMEOUT);

    ret = mbedtls_ssl_setup(&ssl_ctx, &ssl_conf);

    mbedtls_ssl_set_bio(&ssl_ctx, &server_ctx,
                        mbedtls_net_send, NULL, mbedtls_net_recv_timeout);

    mbedtls_ssl_set_timer_cb(&ssl_ctx, &timer,
                             dtls_client_sample_timer_start,
                             dtls_client_sample_timer_get_state);

    ...
}
```

10.8.3.2 DTLS Handshake

DTLS is an encryption protocol designed to secure network communication. A DTLS handshake is the process of initiating a communication session that uses DTLS encryption. To do a DTLS

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handshake, function mbedtls_ssl_handshake() is called. If an error occurs during a DTLS handshake, the API returns the specific error code. If a DTLS session is established successfully, the API returns 0. The details are as follows:

```
void dtls_client_sample(void *param)
{
    ...
    while ((ret = mbedtls_ssl_handshake(&ssl_ctx)) != 0) {
        if (ret == MBEDTLS_ERR_NET_CONN_RESET) {
            PRINTF("\r\n[%s] Peer closed the connection(0x%x)\r\n", __func__, -ret);
            goto end_of_task;
        }

      if ((ret != MBEDTLS_ERR_SSL_WANT_READ) && (ret != MBEDTLS_ERR_SSL_WANT_WRITE))
      {
            PRINTF("\r\n[%s] Failed to do dtls handshake(0x%x)\r\n", __func__, -ret);
            goto end_of_task;
      }
    }
    ...
 }
```

10.8.3.3 Data Transmission

Encryption scrambles data so that only authorized parties can understand the information. While a DTLS session is established, all data must be encrypted to transfer application data. “mbedTLS” provides specific APIs to help encrypt and decrypt data. To write application data, call function mbedtls_ssl_write() of the “mbedTLS” library. The details are as follows:

```
 void dtls_client_sample(void *param)
 {
     ...
     do {
         ...
         while ((ret = mbedtls_ssl_write(&ssl_ctx, data_buffer, len)) <= 0) {
             switch (ret) {
                 case MBEDTLS_ERR_SSL_WANT_READ:
                 case MBEDTLS_ERR_SSL_WANT_WRITE:
                    PRINTF("\r\nNeed more data - mbedtls_ssl_write(0x%x)\r\n", -ret);
                    continue;
                 case MBEDTLS_ERR_SSL_PEER_CLOSE_NOTIFY:
                    PRINTF("\r\nConnection was closed gracefully\r\n");
                    goto end_of_task;
                 case MBEDTLS_ERR_NET_CONN_RESET:
                    PRINTF("\r\nConnection was reset by peer\r\n");
                    goto end_of_task;
                 default:
                    PRINTF("\r\nFailed to write data(0x%x)\r\n", -ret);
                    break;
             }
             goto end_of_task;
         }
         PRINTF("%d bytes written\r\n", len);
     }
     ...
 }
```

To read application data, function mbedtls_ssl_read() of the “mbedTLS” library is called. In this sample, this function is called in dtls_client_sample(). The details are as follows:

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```
void dtls_server_sample(void *param)
{
    ...
    do {
        len = sizeof(data_buffer) - 1;
        memset(data_buffer, 0x00, sizeof(data_buffer));

        PRINTF("< Read from server: ");

        ret = mbedtls_ssl_read(&ssl_ctx, data_buffer, len);
        if (ret <= 0) {
            switch (ret) {
                case MBEDTLS_ERR_SSL_WANT_READ:
                case MBEDTLS_ERR_SSL_WANT_WRITE:
                    PRINTF("\r\nNeed more data - mbedtls_ssl_read(0x%x)\r\n", -ret);
                    continue;
                case MBEDTLS_ERR_SSL_PEER_CLOSE_NOTIFY:
                    PRINTF("\r\nConnection was closed gracefully\r\n");
                    goto end_of_task;
                case MBEDTLS_ERR_NET_CONN_RESET:
                    PRINTF("\r\nConnection was reset by peer\r\n");
                    goto end_of_task;
                default:
                    PRINTF("\r\nFailed to read data(0x%x)\r\n", -ret);
                    break;
            }
            goto end_of_task;
        }

        len = ret;
        PRINTF("%d bytes read\r\n", len);

        PRINTF("> Write to server: ");
        while ((ret = mbedtls_ssl_write(&ssl_ctx, data_buffer, len)) <= 0) {
              ...
        }
    }
    ...
}
```

10.9 DTLS Client in DPM

This section describes how the DTLS client in the DPM sample application is built and works. The DTLS client in the DPM sample application is an example of the simplest DTLS echo client application in DPM mode. DTLS is a cryptographic protocol that provides security for datagram-based applications by allowing them to communicate in a way that is designed to prevent eavesdropping, tampering, or message forgery. The DA16200 SDK can work in DPM mode. The user application requires an additional operation to work in DPM mode. The DA16200 SDK provides the DPM manager for the user network application. The DPM manager supports the user to develop and manage a DTLS network application in Non-DPM and DPM modes.

10.9.1 How to Run

1. Run a DTLS server application on the peer PC and open a DTLS server socket with port number 10199.
2. In the e²studio, import a project for the DTLS Client in the DPM sample application as follows:
   - *~/SDK/apps/common/examples/Network/DTLS_Client_DPM/projects/da16200*
3. Build the DA16200 SDK, download the RTOS image to the DA16200 EVB, and reboot.
4. Use the console command to set up the Wi-Fi station interface.

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5. Set the DTLS server IP address and the port number as created the socket on the peer PC with the following console command and then reboot. These parameters can also be defined in the source code.

   [/DA16200] # nvram.setenv DTLSC_SERVER_IP 192.168.0.11
   [/DA16200] # nvram.setenv DTLSC_SERVER_PORT 10199
   [/DA16200] # reboot

After a connection is made to an AP, the sample application connects to the peer PC.

10.9.2 How It Works

The DA16200 DTLS Client in the DPM sample is a simple echo message. When the DTLS server sends a message, then the DA16200 DTLS client echoes that message to the DTLS server.

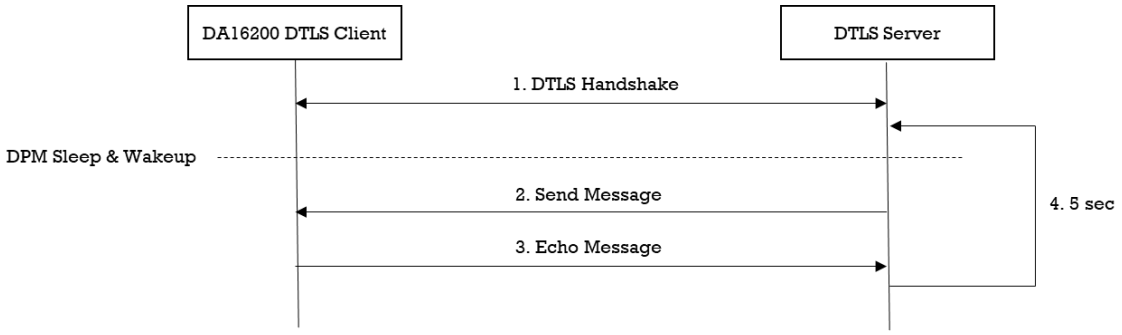

Figure 38: Workflow of DTLS Client in DPM

10.9.3 Sample Code

10.9.3.1 Registration

The DTLS client in the DPM sample application works in DPM mode. The basic code is similar to the DTLS client sample application. There are two differences with the DTLS client sample application:

- An initial callback function is added, named dtls_client_dpm_sample_wakeup_callback() in the code. It is called when the DPM state changes from sleep to wake-up
- Additional user configuration can be stored in RTM

In this sample, DTLS server information is stored.

```
void dtls_client_dpm_sample_init_user_config(dpm_user_config_t *user_config)
{
      const int session_idx = 0;

      //Set Boot init callback
      user_config->bootInitCallback = dtls_client_dpm_sample_init_callback;

      //Set DPM wakeup init callback
      user_config->wakeupInitCallback = dtls_client_dpm_sample_wakeup_callback;

      //Set Error callback
      user_config->errorCallback = dtls_client_dpm_sample_error_callback;

      //Set session type(UDP Client)
      user_config->sessionConfig[session_idx].sessionType = REG_TYPE_UDP_CLIENT;

      //Set local port
      user_config->sessionConfig[session_idx].sessionMyPort =
       DTLS_CLIENT_DPM_SAMPLE_DEF_CLIENT_PORT;
```

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```
        //Set server IP address
        memcpy(user_config->sessionConfig[session_idx].sessionServerIp,
              srv_info.ip_addr, strlen(srv_info.ip_addr));

        //Set server port
        user_config->sessionConfig[session_idx].sessionServerPort = srv_info.port;

        //Set Connection callback
        user_config->sessionConfig[session_idx].sessionConnectCallback =
         dtls_client_dpm_sample_connect_callback;

        //Set Recv callback
        user_config->sessionConfig[session_idx].sessionRecvCallback =
         dtls_client_dpm_sample_recv_callback;

        //Set secure mode
        user_config->sessionConfig[session_idx].supportSecure = pdTRUE;

        //Set secure setup callback
        user_config->sessionConfig[session_idx].sessionSetupSecureCallback =
         dtls_client_dpm_sample_secure_callback;

        //Set user configuration
        user_config->ptrDataFromRetentionMemory = (UCHAR *)&srv_info;
        user_config->sizeOfRetentionMemory =
         sizeof(dtls_client_dpm_sample_svr_info_t);

        return ;
}
```

10.9.3.2 DTLS Setup

To establish a DTLS session, DTLS should be set up. The DA16200 includes an “mbedTLS” library to provide the DTLS protocol. Most APIs that are related to the DTLS protocol are based on an “mbedTLS” library. DTLS is set up by function session_setupSecureCallback(). The details are as shown below. Note that this sample application does not include certificates.

```
void dtls_client_dpm_sample_secure_callback(void *config)
{
        const char *pers = "dtls_client_dpm_sample";
        SECURE_INFO_T *secure_config = (SECURE_INFO_T *)config;

        ret = mbedtls_ssl_config_defaults(secure_config->ssl_conf,
                                          MBEDTLS_SSL_IS_CLIENT,
                                          MBEDTLS_SSL_TRANSPORT_DATAGRAM,
                                          MBEDTLS_SSL_PRESET_DEFAULT);

        ret = dpm_mng_setup_rng(secure_config->ssl_conf);

        //don't care verification in this sample.
        mbedtls_ssl_conf_authmode(secure_config->ssl_conf, MBEDTLS_SSL_VERIFY_NONE);

        //use default value
        mbedtls_ssl_conf_max_frag_len(secure_config->ssl_conf, 0);
        mbedtls_ssl_conf_dtls_anti_replay(secure_config->ssl_conf,
                                          MBEDTLS_SSL_ANTI_REPLAY_ENABLED);
        mbedtls_ssl_conf_read_timeout(secure_config->ssl_conf,
                                      DTLS_CLIENT_DPM_SAMPLE_RECEIVE_TIMEOUT * 10);

        mbedtls_ssl_conf_handshake_timeout(secure_config->ssl_conf,
                                   DTLS_CLIENT_DPM_SAMPLE_HANDSAHKE_MIN_TIMEOUT * 10,
```

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```
                                    DTLS_CLIENT_DPM_SAMPLE_HANDSAHKE_MAX_TIMEOUT * 10);

        ret = mbedtls_ssl_setup(secure_config->ssl_ctx, secure_config->ssl_conf);

        dpm_mng_job_done(); //Done opertaion

        return ;
}
```

10.9.3.3 Data Transmission

The callback function is called when a DTLS packet is received from the DTLS server. In this sample, the received data is printed out and an echo message is sent to the DTLS server. Data is encrypted and decrypted in the callback function.

```
void dtls_client_dpm_sample_recv_callback(void *sock, UCHAR *rx_buf, UINT rx_len,
                                          ULONG rx_ip, ULONG rx_port)
{
        //Display received packet
        PRINTF(" ==> Received Packet(%ld) \n", rx_len);

        status = dpm_mng_send_to_session(SESSION1,
                                         rx_ip,
                                         rx_port,
                                         (char *)rx_buf,
                                         rx_len);
        if (status) {
            PRINTF(RED_COLOR " [%s] Fail send data(session%d,0x%x) \n" CLEAR_COLOR,
                   __func__, SESSION1, status);
        } else {
            //Display sent packet
            PRINTF(" <== Sent Packet(%ld) \n", rx_len);
        }

        dpm_mng_job_done(); //Done opertaion
}
```

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11 Network Examples: MQTT

11.1 Overview

MQTT (Message Queue Telemetry Transport) is an ISO standard (ISO/IEC PRF 20922) publish-subscribe based messaging protocol. It works on top of the TCP/IP protocol. The publisher sends (PUBLISH) messages to the subscriber through the broker. The subscriber needs to keep the connection with the broker by TCP session while the publisher can disconnect the session with the broker after sending a message.

As shown in Figure 39, once the broker receives a message with a specific topic the message is sent to subscribers that already registered with the topic. A subscriber can register with more than one topic. There can be many or no subscribers which registered with a specific topic.

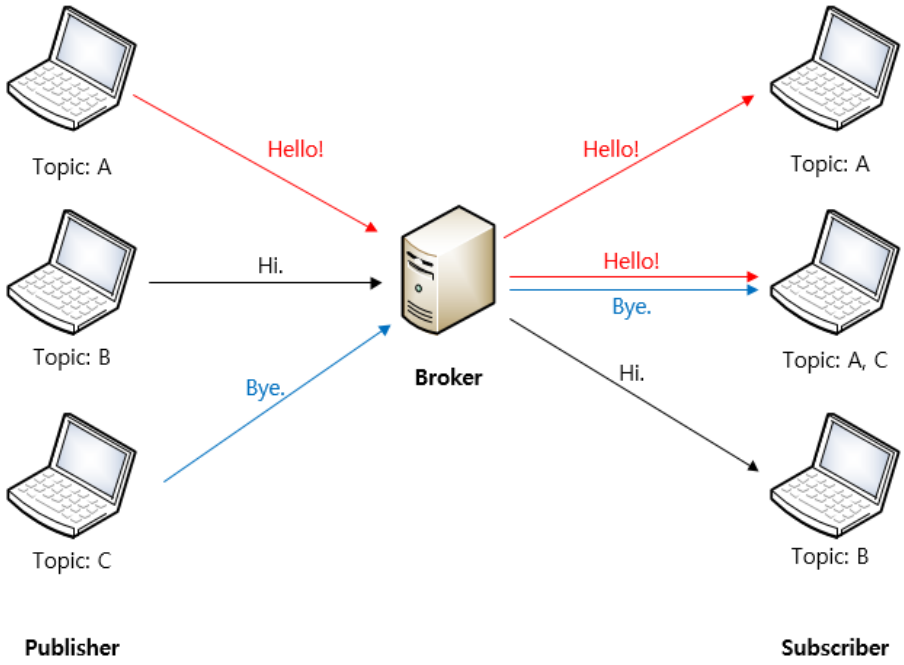

Figure 39: MQTT Messaging Concept

The exchange of MQTT messages supports QoS (Quality of Service). QoS has three levels (0, 1, and 2) and the process of each QoS level is as below.

The DA16200/DA16600 supports both publisher and subscriber functions and allows simultaneous use. The subscriber function supports DPM mode. TLS is available for message encryption.

11.1.1 SDK Build

Source files should be modified in the DA16200/DA16600 SDK to use the MQTT function. To enable the MQTT, modify it as shown below.

```
config_generic_sdk.h
...
#define __SUPPORT_MQTT__            // Support MQTT
```

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11.2 API

11.2.1 APIs for Operating MQTT

The APIs listed in Table 13 are used to create or terminate the MQTT thread, to check the status, and to publish a message. The configuration to execute MQTT protocols is explained in the next section.

Table 13: APIs for Operating MQTT

Item		Description
int mqtt_client_start(void)		
Return		If succeeded, returns 0. If failed, returns an error code.
Description		Create the MQTT client thread.
int mqtt_client_stop(void)		
Return		If succeeded, returns 0. If there is no thread to terminate, returns -1.
Description		Terminate the MQTT client thread.
int mqtt_client_check_conn(void)		
Return		1 (true): Connected to a broker. 0 (false): Not connected.
Description		Check whether the MQTT session is connected.
int mqtt_client_send_message(char *top, char *publish)		
Return		0: Succeeded to publish. -1: Failed because MQTT is not connected. -2: Failed because the previous message send is in progress. -3: Failed because MQTT topic is missing. Other: Failed due to other cause. See enum “mqtt_client_error_code” to identify the cause.
Parameter	top	Topic (if NULL, the MQTT publisher sends a PUBLISH message with the topic stored in NVRAM.)
	publish	Message to be published.
Description		Publisher sends an MQTT message (PUBLISH).
int mqtt_client_send_message_with_qos(char *top, char *publish, timeout)		
Return		0: Succeeded to publish. -1: Failed to publish because Publisher is not ready to send. -2: Failed to publish because the timeout expired.
Parameter	top	Topic (if NULL, the MQTT module sends a PUBLISH message with the topic stored in NVRAM.)
	publish	Message to be published.
	timeout	Timeout to wait for a previous QoS=1/2 Message to process completely (unit: 10 ms).
Description		Publisher sends an MQTT message (PUBLISH) with a timeout check.
int mqtt_client_unsub_topic(char *topic)		
Parameter	topic	Topic to unsubscribe
Return		0: Succeeded to unsubscribe. 4: Failed because MQTT is not connected.

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Item	Description
	3: Failed because the topic is NULL 1: Failed because of memory alloc failure Other: Failed due to other cause. See enum “mqtt_client_error_code” to identify the cause.
Description	Unsubscribe from the topic specified. Invoke this function only when MQTT client is in a connected state with Broker.

11.2.2 APIs for Configure MQTT Messaging

With NVRAM items, the user can configure MQTT messaging. This allows configuring the publisher and the subscriber.

Table 14: APIs for Configure MQTT Message

Item		Description
int mqtt_client_config_initialize(void)		
Return		If succeeded, returns 0 (MOSQ_ERR_SUCCESS. If failed, returns an error code.
Description		Reset all MQTT Configurations.
void mqtt_sub_callback_set(void (*user_cb)(void))		
Parameter	user_cb	User callback function to set
Return		None
Description		Register a callback function that is invoked when a MQTT Subscriber is connected with a Broker.
void mqtt_pub_callback_set(void (*user_cb)(void))		
Parameter	user_cb	User callback function to set
Return		None
Description		Register a callback function that is invoked when publishing a message is done.
void mqtt_msg_callback_set(void (*user_cb)(const char *buf, int len, const char *topic))		
Parameter	user_cb	User callback function to set buf: PUBLISH message received len: PUBLISH message length topic: the topic of the PUBLISH message received
Return		None
Description		Register a callback function that is invoked when a PUBLISH message arrives.
void mqtt_sub_disconn_cb_set(void (*user_cb)(void));		
Parameter	user_cb	User callback function to set
Return		None
Description		Register a callback function that is invoked when the MQTT client is disconnected.
void mqtt_sub_disconn2_cb_set(void (*user_cb)(void));		
Parameter	user_cb	User callback function to set
Return		None

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Item		Description
Description		- Register callback function called when MQTT Subscriber is disconnected by receiving a message with invalid unsupported length if the connection is clean_session=0 and qos > 0. - On receipt of this callback, application needs to clear the message in Broker by connecting with clean_sesion=1. - To use this API, __MQTT_CLEAN_SESSION_MODE_SUPPORT__ should be enabled.
void mqtt_subscribe_callback_set(void (*user_cb)(void));		
Parameter	user_cb	User callback function to set
Return		None
Description		Register a callback function that is invoked when a SUBSCRIBE request to a topic is finished
void mqtt_unsubscribe_callback_set(void (*user_cb)(void));		
Parameter	user_cb	User callback function to set
Return		None
Description		Register a callback function that is invoked when an UNSUBSCRIBE request is finished

Table 15: MQTT Messaging Configuration (String Type)

Name	Description	Example
DA16X_CONF_STR_MQTT_BROKER_IP	Broker IP address (or URI)	da16x_set_config_str(DA16X_CONF_STR_MQTT_BROKER_IP, “192.168.0.1”);
DA16X_CONF_STR_MQTT_SUB_TOPIC	Subscriber topic (previous topics will be removed)	da16x_set_config_str(DA16X_CONF_STR_MQTT_SUB_TOPIC, topic);
DA16X_CONF_STR_MQTT_SUB_TOPIC_ADD	Subscriber topic to add (up to four)	da16x_set_config_str(DA16X_CONF_STR_MQTT_SUB_TOPIC_ADD, topic);
DA16X_CONF_STR_MQTT_SUB_TOPIC_DEL	Subscriber topic to remove	da16x_set_config_str(DA16X_CONF_STR_MQTT_SUB_TOPIC_DEL, topic);
DA16X_CONF_STR_MQTT_PUB_TOPIC	Topic to publish	da16x_set_config_str(DA16X_CONF_STR_MQTT_PUB_PUB_TOPIC, “pub_topic”);
DA16X_CONF_STR_MQTT_USERNAME	Username to log in to a broker	da16x_set_config_str(DA16X_CONF_STR_MQTT_USERNAME, “mqtt_id”);
DA16X_CONF_STR_MQTT_PASSWORD	Password to login to a broker	da16x_set_config_str(DA16X_CONF_STR_MQTT_PASSWORD, “mqtt_password”);
DA16X_CONF_STR_MQTT_WILL_TOPIC	Will Topic	da16x_set_config_str(DA16X_CONF_STR_MQTT_WILL_TOPIC, “will_topic”);
DA16X_CONF_STR_MQTT_WILL_MSG	Will Message	da16x_set_config_str(DA16X_CONF_STR_MQTT_WILL_MSG, “will_msg”);
DA16X_CONF_STR_MQTT_SUB_CLIENT_ID	MQTT client ID	da16x_set_config_str(DA16X_CONF_STR_MQTT_SUB_CLIENT_ID, “sub_id”);
DA16X_CONF_STR_MQTT_TLS_SNI	MQTT TLS SNI (Server Name Indication)	da16x_set_config_str(DA16X_CONF_STR_MQTT_TLS_SNI, “sni_str”)

Note 1 Up to four subscriber topics can be registered, and only one publisher topic can be registered.

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Table 16: MQTT Messaging Configuration (Integer Type)

Name	Description	Example
DA16X_CONF_INT_MQTT_SUB	MQTT operation (0: stop, 1: start)	da16x_set_config_int(DA16X_CONF_INT_MQTT_SUB, 1);
DA16X_CONF_INT_MQTT_AUTO	MQTT Auto-start at booting system (0: disable, 1: enable)	da16x_set_config_int(DA16X_CONF_INT_MQTT_AUTO, 1);
DA16X_CONF_INT_MQTT_PORT	Broker port number	da16x_set_config_int(DA16X_CONF_INT_MQTT_PORT, 8883);
DA16X_CONF_INT_MQTT_QOS	QoS level (0~2)	da16x_set_config_int(DA16X_CONF_INT_MQTT_QOS, 2);
DA16X_CONF_INT_MQTT_TLS	TLS (0: disable, 1: enable)	da16x_set_config_int(DA16X_CONF_INT_MQTT_TLS, 1);
DA16X_CONF_INT_MQTT_WILL_QOS	QoS level of will messages (0~2)	da16x_set_config_int(DA16X_CONF_INT_MQTT_WILL_QOS, 1);
DA16X_CONF_INT_MQTT_PING_PERIOD	MQTT ping period (secs)	da16x_set_config_int(DA16X_CONF_INT_MQTT_PING_PERIOD, 86400);
DA16X_CONF_INT_MQTT_VER311	MQTT protocol : 1 (v3.1.1) / 0 (v3.1)	da16x_set_config_int(DA16X_CONF_INT_MQTT_VER311, 1)
DA16X_CONF_INT_MQTT_TLS_INCOMING	TLS incoming buffer size: default (1024*4), min (1024*2), max (1024*8)	da16x_set_config_int(DA16X_CONF_INT_MQTT_TLS_INCOMING, 1024*4)
DA16X_CONF_INT_MQTT_TLS_OUTGOING	TLS outgoing buffer size: default (1024*4), min (1024*2), max (1024*8)	da16x_set_config_int(DA16X_CONF_INT_MQTT_TLS_OUTGOING, 1024*4)
DA16X_CONF_INT_MQTT_TLS_AUTHMODE	TLS peer certificate verification mode: 0 (not verify), 1 (optional), 2 (required), default is 1	da16x_set_config_int(DA16X_CONF_INT_MQTT_TLS_AUTHMODE, 1)
DA16X_CONF_INT_MQTT_CLEAN_SESSION	MQTT Clean Session mode (1: clean the previous session, 0: do not clean the previous session)	da16x_set_config_int(DA16X_CONF_INT_MQTT_CLEAN_SESSION, 1);

11.3 Test

This section explains how to test the MQTT function on the DA1620/DA16600 debug console window.

11.3.1 Test Environment

For this test the Mosquitto MQTT broker is used, which can be downloaded from the following URL: https://mosquitto.org/download/. If the broker cannot be installed, use the one provided by Renesas Electronics. Extract and run it on local Windows PC.

11.3.2 Setup

Open a command window and go to the Mosquitto folder.

1. Run a broker.

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```
mosquitto -v -p <Port Number>
```

```
C:₩mosquitto>mosquitto -v -p 1884
1582173416: mosquitto version 1.4.14 (build date 11/07/2017  0:03:18.53) starting
1582173416: Using default config.
1582173416: Opening ipv6 listen socket on port 1884.
1582173416: Opening ipv4 listen socket on port 1884.
```

2. Open a new command window and run a subscriber.

```
mosquitto_sub -h <Broker IP> -p <Port Number> -t <Topic>
```

```
C:₩mosquitto>mosquitto_sub -h 172.16.30.163 -p 1884 -t da16k
```

The following message is shown in the broker window.

```
C:₩mosquitto>mosquitto -v -p 1884
1582173276: mosquitto version 1.4.14 (build date 11/07/2017  0:03:18.53) starting
1582173276: Using default config.
1582173276: Opening ipv6 listen socket on port 1884.
1582173276: Opening ipv4 listen socket on port 1884.
1582173309: New connection from 172.16.30.163 on port 1884.
1582173309: New client connected from 172.16.30.163 as mosqsub|13800-KR-ENG-LT (c1, k60).
1582173309: Sending CONNACK to mosqsub|13800-KR-ENG-LT (0, 0)
1582173309: Received SUBSCRIBE from mosqsub|13800-KR-ENG-LT
1582173309:     da16k (QoS 0)
1582173309: mosqsub|13800-KR-ENG-LT 0 da16k
1582173309: Sending SUBACK to mosqsub|13800-KR-ENG-LT
```

3. Open a new command window and publish a message.

```
mosquitto_pub -h <Broker IP> -p <Port Number> -t <Topic> -m "<Message>"
```

```
C:₩mosquitto>mosquitto_pub -h 172.16.30.163 -p 1884 -t da16k -m "Hello World!"
```

The following message is shown in the broker window.

```
582173567: New connection from 172.16.30.163 on port 1884.
582173567: New client connected from 172.16.30.163 as mosqpub|3508-KR-ENG-LT- (c1, k60).
582173567: Sending CONNACK to mosqpub|3508-KR-ENG-LT- (0, 0)
582173567: Received PUBLISH from mosqpub|3508-KR-ENG-LT- (d0, q0, r0, m0, 'da16k', ... (12 bytes))
582173567: Sending PUBLISH to mosqsub|17076-KR-ENG-LT (d0, q0, r0, m0, 'da16k', ... (12 bytes))
582173567: Received DISCONNECT from mosqpub|3508-KR-ENG-LT-
582173567: Client mosqpub|3508-KR-ENG-LT- disconnected.
```

The subscriber receives the message.

```
C:₩mosquitto>mosquitto_sub -h 172.16.30.163 -p 1884 -t da16k
Hello World!
```

11.3.3 Certificate

DA16200/DA16600 provides methods to store certificates in the serial flash with the use of console commands.

11.3.3.1 Certificate Commands

1. Store a CA certificate.

```
[/DA16200/NET]# net
[/DA16200/NET]# cert 0 // for SDK v3.2.3.0 or higher, use “cert write ca1”
Typing data: (certificate value)
Cancel - CTRL+D, End of Input - CTRL+C or CTRL+Z
```

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```
// Copy & paste certificate data in the terminal window and click "CTRL+C" or "CTRL+Z"
(see Section 11.3.3.2)
```

2. Store a client certificate.

```
[/DA16200/NET]# cert 1 // for SDK v3.2.3.0 or higher, use "cert write cert1"
Typing data: (certificate value)
Cancel - CTRL+D, End of Input - CTRL+C or CTRL+Z
// Copy & paste certificate data in the terminal window and click "CTRL+C" or "CTRL+Z"
(see Section 11.3.3.2)
```

3. Store a client key.

```
[/DA16200/NET]# cert 2 // for SDK v3.2.3.0 or higher, use "cert write key1"
Typing data: (certificate value)
Cancel - CTRL+D, End of Input - CTRL+C or CTRL+Z
// Copy & paste certificate data in the terminal window and click "CTRL+C" or "CTRL+Z"
(see Section 11.3.3.2)
```

4. After adding cert/keys, check if they are successfully stored.0.

```
[/DA16200/NET]# cert // for SDK v3.2.3.0 or higher, use "cert status"#1 (MQTT,
Enterprise)
Root CA: O
Certificate: O
Private Key: O
DH Parameter: X
#2 (HTTPs, CoAPs Client)
Root CA: X
Certificate: X
Private Key: X
DH Parameter: X

// in SDK 3.x, cert status is shown as below
[/DA16200/NET] # cert status

#1:
  For MQTT, CoAPs Client
  - Root CA     : Found
  - Certificate : Found
  - Private Key : Found
  - DH Parameter: Empty

#2:
  For HTTPs, OTA
  - Root CA     : Empty
  - Certificate : Empty
  - Private Key : Empty
  - DH Parameter: Empty
```

In case remove all the credentials stored:

```
[/DA16200/NET]# cert 3 // in SDK v3.x, use "cert del all"
```

11.3.3.2 CA, Client Cert, and Client Key

- Cert 0: CA


```
-----BEGIN CERTIFICATE-----
MIID+TCCAuGgAwIBAgIJANqqHCazDkkOMA0GCSqGSIb3DQEBCwUAMIGSMQswCQYD
VQQGEwJVUzETMBEGA1UECAwKQ2FsaWZvcm5pYTEUMBIGA1UEBwwLU2FudGEgQ2xh
cmExFzAVBgNVBAoMDldpLUZpIEFsbGlhbmNlMR0wGwYDVQQDDBRXRkEgUm9vdCBD
ZXJ0aWZpY2F0ZTEgMB4GCSqGSIb3DQEJARYRc3VwcG9ydEB3aS1maS5vcmcwHhcN
MTMwMzExMTkwMjI2WhcNMjMwMzA5MTkwMjI2WjCBkjELMAkGA1UEBhMCVVMxEzAR
```


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```
BgNVBAgMCkNhbGlmb3JuaWExFDASBgNVBAcMC1NhbnRhIENsYXJhMRcwFQYDVQQK
DA5XaS1GaSBBbGxpYW5jZTEdMBsGA1UEAwwUV0ZBIFJvb3QgQ2VydGlmaWNhdGUx
IDAeBgkqhkiG9w0BCQEWEXN1cHBvcnRAd2ktZmkub3JnMIIBIjANBgkqhkiG9w0B
AQEFAAOCAQ8AMIIBCgKCAQEA6TOCu20m+9zLZITYAhGmtxwyJQ/1xytXSQJYX8LN
YUS/N3HG2QAQ4GKDh7DPDI13zhdc0yOUE1CIOXa1ETKbHIU9xABrL7KfX2HCQ1nC
PqRPiW9/wgQch8Aw7g/0rXmg1zewPJ36zKnq5/5Q1uyd8YfaXBzhxm1IYlwTKMlC
ixDFcAeVqHb74mAcdel1lxdagHvaL56fpUExm7GyMGXYd+Q2vYa/o1UwCMGfMOj6
FLHwKpy62KCoK3016HlWUlbpg8YGpLDt2BB4LzxmPfyH2x+Xj75mAcllOxx7GK0r
cGPpINRsr4vgoltm4Bh1eIW57h+gXoFfHCJLMG66uhU/2QIDAQABo1AwTjAdBgNV
HQ4EFgQUCwPCPlSiKL0+Sd5y8V+Oqw6XZ4IwHwYDVR0jBBgwFoAUCwPCPlSiKL0+
Sd5y8V+Oqw6XZ4IwDAYDVR0TBAUwAwEB/zANBgkqhkiG9w0BAQsFAAOCAQEAsNxO
z9DXb7TkNFKtPOY/7lZig4Ztdu6Lgf6qEUOvJGW/Bw1WxlPMjpPk9oI+JdR8ZZ4B
9QhE+LZhg6SJbjK+VJqUcTvnXWdg0e8CgeUw718GNZithIElWYK3Kh1cSo3sJt0P
z9CiJfjwtBDwsdAqC9zV9tgp09QkEkav84X20VxaITa3H1QuK/LWSn/ORrzcX0Il
10YoF6Hz3ZWa65mUoMzd8DYtCyGtcbYrSt+NMCqRB186PDQn5XBCytgF8VuiCyyk
Z04hqHLzAFc21P9yhwKGi3BHD/Sep8fvr9y4VpMIqHQm2jaFPxY1VxhPSV+UHoE1
fCPitIJTp/iXi7uXTQ==
-----END CERTIFICATE-----
```


- Cert 1: Client Cert


```
-----BEGIN CERTIFICATE-----
MIIEBTCCAu2gAwIBAgICEEYwDQYJKoZIhvcNAQELBQAwgZIxCzAJBgNVBAYTAlVT
MRMwEQYDVQQIDApDYWxpZm9ybmlhMRQwEgYDVQQHDAtTYW50YSBDbGFyYTEXMBUG
A1UECgwOV2ktRmkgQWxsaWFuY2UxHTAbBgNVBAMMFFdGQSBSb290IENlcnRpZmlj
YXRlMSAwHgYJKoZIhvcNAQkBFhFzdXBwb3J0QHdpLWZpLm9yZzAeFw0xMzA1MTAy
MzQ0NTFaFw0yMzA1MDgyMzQ0NTFaMH4xCzAJBgNVBAYTAlVTMRMwEQYDVQQIDApD
YWxpZm9ybmlhMRcwFQYDVQQKDA5XaS1GaSBBbGxpYW5jZTEfMB0GA1UEAwwWQ2xp
ZW50IENlcnRpZmljYXRlIElETDEgMB4GCSqGSIb3DQEJARYRc3VwcG9ydEB3aS1m
aS5vcmcwggEiMA0GCSqGSIb3DQEBAQUAA4IBDwAwggEKAoIBAQDco7kQ4W2b/fBw
2ZgSAXVWBCmJW0yax8K682kRiHlB1aJ5Im8rTEktZlPDQVhoO3Ur+Ij9Y8ukD3Hq
CMa95T1a3Ly9lhDIME/VRqRgZRGa/FC/jkiK9u9SgIXPZqJk1s/JVG7a7deC8BvK
iqIFhXoHl0N4nJxwVA8kag48dXbrTxrOH26C9qwU85iS/c1ozHJMmq052WPSQZII
Sq8+VmxlCbbXxQ7kU2oZkxDqW3hMI3OPS80s8q4tMzuitvzFO0JvAHgh4IFyE7yg
nIE7+lM9f3EwzECw9nEBdL7AvfnYLhlIEI8S8wZTUpnd8XA5Qs7Qa4rINuqI273Z
IWJLh9v/AgMBAAGjeDB2MA8GA1UdEwEB/wQFMAMCAQAwCwYDVR0PBAQDAgXgMBYG
A1UdJQEB/wQMMAoGCCsGAQUFBwMCMB0GA1UdDgQWBBQtC2mx8POhZRfB+sj4wX1Z
OzdrCzAfBgNVHSMEGDAWgBQLA8I+VKIovT5J3nLxX46rDpdngjANBgkqhkiG9w0B
AQsFAAOCAQEAsvHJ+J2YTCsEA69vjSmsGoJ2iEXDuHI+57jIo+8qRVK/m1is1eiU
AefExDtxxKTEPPtourlYO8A4i7oep9T43Be8nwVZdmxzfu14cdLKQrE+viCuHQTc
BLSoAv6/SZa3MeIRkkDSPtCPTJ/Pp+VYPK8gPlc9pwEs/KLgFxK/Sq6RDNjTPs6J
MChxi1iSdUES8mz3JDhQ2RQWVuibPorhgVqNTyXBjFUbYxTVl3hBCtK/Bd4IyFTX
Li90XXHseNbj2sHu3PFBU7PG5mhKQMUOYqvQzEDIXT6SDA+PrepqrwXn/BL861K6
GV4LcfKBg0HHdW9gJByZCN02igFTw56Kzg==
-----END CERTIFICATE-----
```


11.3.4 Publisher

11.3.4.1 QoS=0 Message

This section gives an example of publishing a QoS=0 message.

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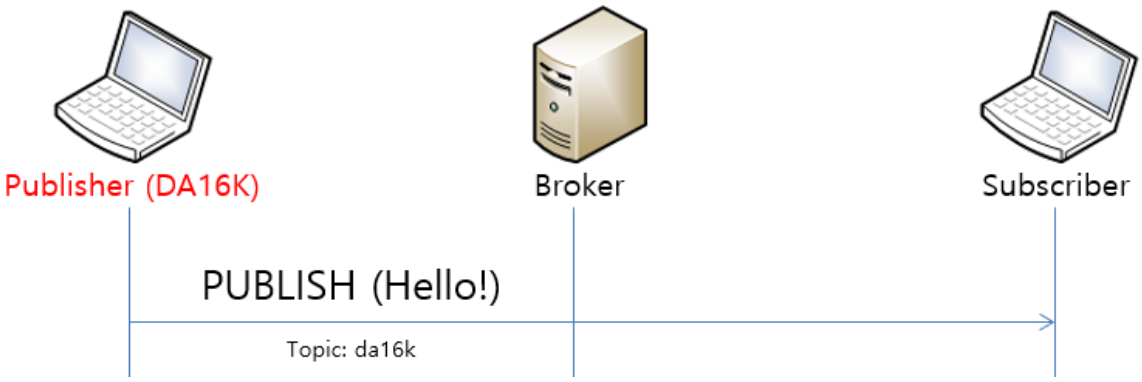

Figure 40: Publish QoS=0 Message

1. After the DA16200/DA16600 EVB is connected to an AP, configure the parameters, and publish a message.

```
[/DA16200]# net
[/DA16200/NET]# mqtt_config broker <Broker IP>
[/DA16200/NET]# mqtt_config port <Port Number>
[/DA16200/NET]# mqtt_config pub_topic <Topic>
[/DA16200/NET]# mqtt_client start
>>> MQTT Client connection OK (da16x_FFFE)

[/DA16200/NET]# mqtt_client -m <Message>
…
[/DA16200/NET]# mqtt_client stop
```

Optionally, “client_id” can also be set with the following command:

[/DA16200/NET]# mqtt_config client_id <client_id_string>

For example, mqtt_config client_id abcd1111

client_id should be unique per each device. By default, client_id is generated internally as “da16x_<the last 2 bytes of mac address>”. For example, da16x_FCFA.

2. When message transmission -m “Hello!” is successful, the following messages will be displayed:

`Hello! (Send, Len: 6, Topic: da16k, Message ID: 1)` The following syntax allows to send a message with a new topic:

```
[/DA16200/NET] mqtt_client -m <Message> <NewTopic>
```

If the previous parameters for broker, port, and topics are not changed, then no action is required to set the parameters for the publication of every message.

* The max length of the console command is 158. To send a longer PUBLISH, write the following command:

```
[/DA16200/NET] mqtt_client -l
Typing data: (MQTT Publisher message)
      Cancel - CTRL+D, End of Input - CTRL+C or CTRL+Z
12345678901234567890123456789012345678901234567890123456789012345678901234567
890123456789012345678901234567890123456789012345678901234567890123456789012345
678901234567890123456789012345678901234567890123456789012345678901234567890123
4567890123456789 …
```

Use the keyboard combinations Ctrl+C or Ctrl+Z to send the message.

11.3.4.2 QoS=1/2 Message

This section gives an example of publishing a QoS=1/2 Message.

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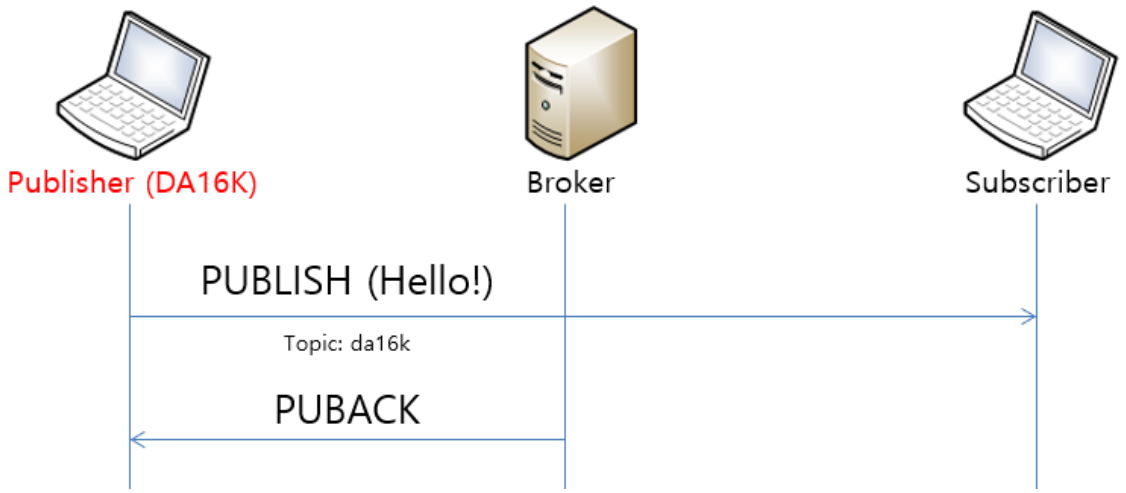

Figure 41: Publish QoS 1 Message

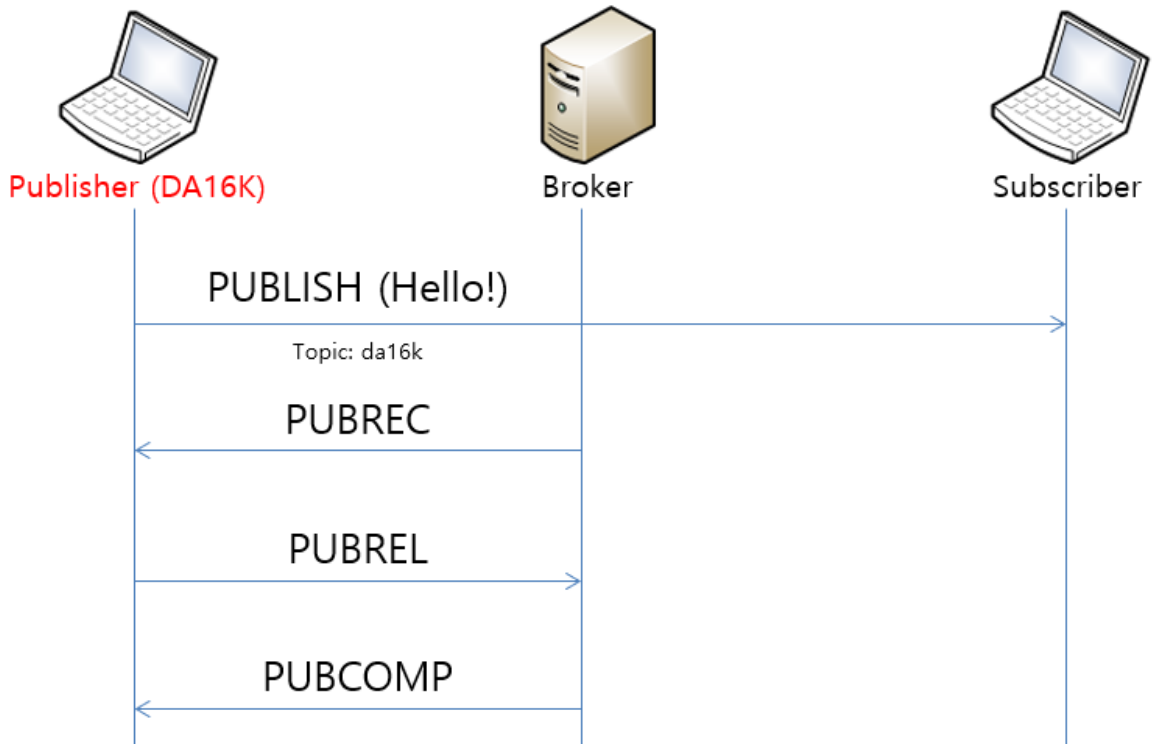

Figure 42: Publish QoS 2 Message

- Configure the parameters and publish a message.

```
[/DA16200/NET]# mqtt_config broker <Broker IP>
[/DA16200/NET]# mqtt_config port <Port Number>
[/DA16200/NET]# mqtt_config pub_topic <Topic>
[/DA16200/NET]# mqtt_config qos <QoS Level>
[/DA16200/NET]# mqtt_client start
>>> MQTT Client connection OK (da16x_FFFE)

[/DA16200/NET]# mqtt_client -m <Message>
```


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```
1582175804: Received PUBLISH from PUB-da16x_FD26 (d0, q1, r0, m1, 'da16k', ... (6 bytes))
1582175804: Sending PUBACK to PUB-da16x_FD26 (Mid: 1)
```

```
1582175859: Received PUBLISH from PUB-da16x_FD26 (d0, q2, r0, m1, 'da16k', ... (6 bytes))
1582175859: Sending PUBREC to PUB-da16x_FD26 (Mid: 1)
1582175859: Received PUBREL from PUB-da16x_FD26 (Mid: 1)
1582175859: Sending PUBCOMP to PUB-da16x_FD26 (Mid: 1)
```

Figure 43: Configure Parameters and Publish Message

11.3.4.3 MQTT over TLS

The DA16200/DA16600 SDK provides a TLS encrypted session for secure MQTT messages.

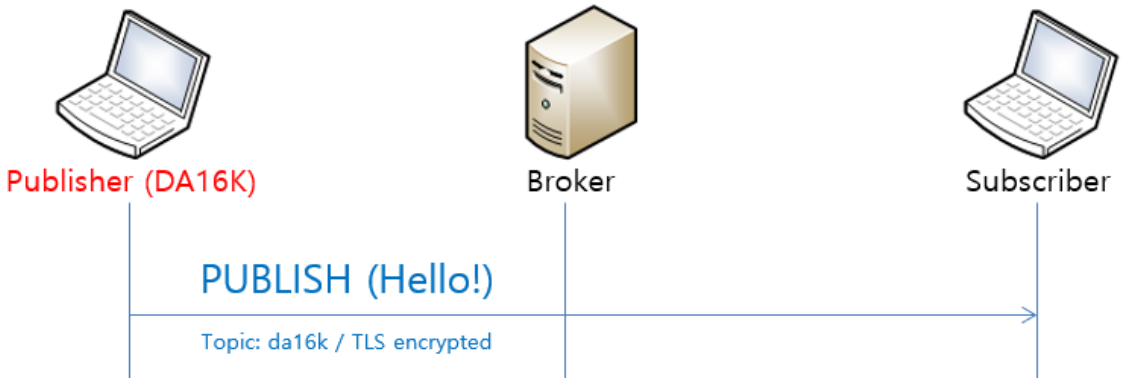

Figure 44: Publish Secure Message

NOTE
It is required to store certificates in the DA1620/DA16600 EVK to use TLS encryption. This procedure is explained in Section 11.3.3.

1. Run a broker with a secure port.

```
mosquitto –c mosquitto.conf -p <Port Number> -v
```

```
C:₩mosquitto>mosquitto -c mosquitto.conf -p 8883 -v
1582174980: mosquitto version 1.4.14 (build date 11/07/2017  0:03:18.53) starting
1582174980: Config loaded from mosquitto.conf.
1582174980: Opening ipv6 listen socket on port 8883.
1582174980: Opening ipv4 listen socket on port 8883.
```

2. Run a subscriber.

```
mosquitto_sub -h <Broker IP> -p <Port> --cafile <CA Certificate> --cert <Client Certificate> --key
<Client Private Key> --tls-version <TLS Protocol Version> --insecure -t <Topic>
```

```
C:₩mosquitto>mosquitto_sub -h 172.16.30.163 -p 8883 --cafile cas.pem --cert wifiuser.pem --key wifiuser.key --tls-ver
sion tlsv1 --insecure -t da16k
```

3. Set the current time in the DA16200/DA16600 EVB to check if the certificate is valid.
   (If SNTP for time sync is needed, input the command “net.sntp enable” to get the current time.)

```
[/DA16200]# time set <yyyy-mm-dd> <hh:mm:ss>
```

4. Store three Certificates (see Section 11.3.3.1) in the DUT, and then follow the steps below.

```
[/DA16200/NET]# mqtt_config broker <Broker IP>
[/DA16200/NET]# mqtt_config port <Port Number>
[/DA16200/NET]# mqtt_config pub_topic <Topic>
[/DA16200/NET]# mqtt_config tls 1
[/DA16200/NET]# mqtt_client start
>>> MQTT Client connection OK (da16x_FFFE)
```

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```
[/DA16200/NET]# mqtt_client -m <Message>
```

11.3.4.4 Username and Password

1. Set up a username and password to authenticate users.

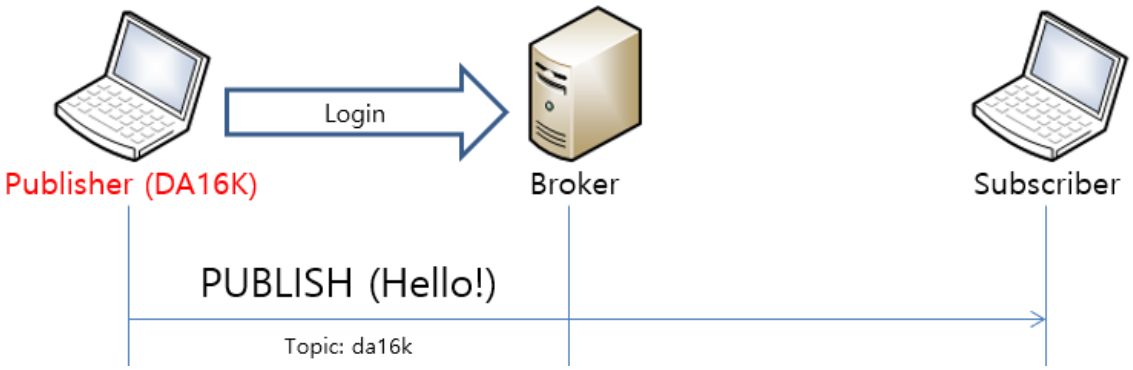

Figure 45: User Login

2. Run a broker with a secure port. It needs to prepare the configuration file.

```
mosquitto -c <Config File> -p <Port> -v
```

```
C:₩mosquitto>mosquitto -c mosq_idpw.conf -p 1900 -v
1582176530: mosquitto version 1.4.14 (build date 11/07/2017  0:03:18.53) starting
1582176530: Config loaded from mosq_idpw.conf.
1582176530: Opening ipv6 listen socket on port 1900.
1582176530: Opening ipv4 listen socket on port 1900.
```

In the Mosquitto package provided by Renesas Electronics, file mosq_idpw.conf is used for the <Config File> parameter, and user accounts are registered in file p1.txt.

3. Add a new account in this file with the following command:

```
mosquitto_passwd.exe -b p1.txt <username> <password>
```

4. At the Mosquitto command prompt, run the mosquito_sub command to log in successfully to the broker.

```
mosquitto_sub -h <broker_ip> -p <port> -t <topic> -u <id> -P <pass>
```

5. On mqtt_client (DUT), set the username and password, and start mqtt_client.

```
[/DA16200/NET]# mqtt_config broker <Broker IP>
[/DA16200/NET]# mqtt_config port <Port Number>
[/DA16200/NET]# mqtt_config pub_topic <Topic>
[/DA16200/NET]# mqtt_config tls 0
[/DA16200/NET]# mqtt_config username <Username>
[/DA16200/NET]# mqtt_config password <Password>
[/DA16200/NET]# mqtt_client start
>>> MQTT Client connection OK (da16x_FFFE)

[/DA16200/NET]# mqtt_client -m <Message>
```

NOTE

- The max length of the console command is 158 so to type in a password exceeding the limit of the console, use the command “mqtt_config long_password”
- The max length of the buffer is currently 160 for a password, 64 for a username. If it needs to change max length, modify MQTT_USERNAME_MAX_LEN or MQTT_PASSWORD_MAX_LEN.

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11.3.5 Subscriber

11.3.5.1 Setup

1. Configure the parameters and start the subscriber.

```
[/DA16200/NET]# mqtt_config broker <Broker IP>
[/DA16200/NET]# mqtt_config port <Port Number>
[/DA16200/NET]# mqtt_config sub_topic 1 <Topic>
[/DA16200/NET]# mqtt_client start
>>> MQTT Client connection OK (da16x_FFFE)
…
[/DA16200/NET]# mqtt_client stop
```

2. Multiple topics can be registered. Add the parameter for the number of topics in the command (up to four).

```
[/DA16200/NET]# mqtt_client stop
[/DA16200/NET]# mqtt_config sub_topic <Topic count> <Topic#1> <Topic#2> …
[/DA16200/NET]# mqtt_client start
>>> MQTT Client connection OK (da16x_FFFE)
…
[/DA16200/NET]# mqtt_config sub_topic_add <New topic>
[/DA16200/NET]# mqtt_config sub_topic_del <Topic to remove>
```

11.3.5.2 MQTT over TLS

Set the current time in the DA16200/DA16600 EVB to check if the certificate is valid. (If SNTP is auto started during boot, skip this step.)

```
[/DA16200]# time set <yyyy-mm-dd> <hh:mm:ss>
```

1. Run the broker as below.

```
mosquitto –c mosquitto.conf -p <Port Number> -v
```

2. Add three Certificates (see Section 11.3.3.1) for the DUT, and then do the steps below.

```
[/DA16200/NET]# mqtt_config broker <Broker IP>
[/DA16200/NET]# mqtt_config port <Port Number>
[/DA16200/NET]# mqtt_config sub_topic 1 <Topic>
[/DA16200/NET]# mqtt_config tls 1
[/DA16200/NET]# mqtt_client start
>>> MQTT Client connection OK (da16x_FFFE)
```

3. Run a publisher on the local PC.

```
mosquitto_pub -h <Broker IP> -p <Port> --cafile <CA Certificate> --cert <Client Certificate> --key
<Client Private Key> --tls-version <TLS Protocol Version> -t <Topic> --insecure –m <message>

Example: mosquitto_pub -h 192.168.0.101 -p 1884 --cafile cas.pem --cert wifiuser.pem --key
wifiuser.key --tls-version tlsv1 -t da16k --insecure -m "hello"
```

11.3.5.3 Username and Password

1. DUT: Set username and password.

```
[/DA16200/NET]# mqtt_config broker <Broker IP>
[/DA16200/NET]# mqtt_config port <Port Number>
[/DA16200/NET]# mqtt_config sub_topic 1 <Topic>
[/DA16200/NET]# mqtt_config tls 0
[/DA16200/NET]# mqtt_config username <Username>
[/DA16200/NET]# mqtt_config password <Password>
[/DA16200/NET]# mqtt_client start
>>> MQTT Client connection OK (da16x_FFFE)
```

2. In the Mosquitto package provided by Renesas Electronics, file mosq_idpw.conf is used for the <Config File> parameter and user accounts are registered in file p1.txt. Add a new account in this file with the following command.

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```
mosquitto_pub -h [Broker IP] -p [port] -t [topic] -m <message> -u [id] -P [password]

Example:

mosquitto_pub -h 192.168.0.101 -p 1884 -t da16k -u mike -P 1234 -m hello
```

11.3.5.4 WILL

1. Sub#1 (DUT): Set the will message.

```
[/DA16200/NET]# mqtt_config broker <Broker IP>
[/DA16200/NET]# mqtt_config port <Port Number>
[/DA16200/NET]# mqtt_config sub_topic 1 <Topic>
[/DA16200/NET]# mqtt_config will_topic <Topic>
[/DA16200/NET]# mqtt_config will_message <Message>
[/DA16200/NET]# mqtt_config will_qos <QoS Level>
[/DA16200/NET]# mqtt_client start
>>> MQTT Client connection OK (da16x_FFFE)
```

2. Broker: Write the following command.

```
>mosquitto -v -p 1884
```

3. Sub#2 (PC): Write the following command.

```
>mosquitto_sub -h 192.168.0.101 -t da16k -p 1884 -q 0
```

4. Sub#1 (DUT): Try an unexpected disconnection.

```
[/DA16200/NET]# reset

>>> Network Interface (wlan0): DOWN
 [mqtt_subscriber_main] Request mqtt_restart
[wpa_supplicant_event_disassoc] CTRL-EVENT-DISCONNECTED bssid=ec:08:6b:d6:53:62
reason=3 locally_generated=1

DA16200 ROM-Boot [ffffc000]
[MROM]
```

5. Sub#2 (PC): Wait until the following will message is printed.

```
>mosquitto_sub -h 192.168.0.101 -t da16k -p 1884 -q 2
imwill
```

11.3.6 MQTT Pub/Sub Test with DPM and TLS

In this test, the Pub and Sub are run with the DPM mode enabled.

1. Broker: Run with TLS enabled.

```
>mosquitto -c mosquitto.conf -p 8883 -v
```

2. Sub#2 (PC): Write the following command.

```
>mosquitto_sub -h 192.168.0.101 -p 8883 --cafile cas.pem --cert wifiuser.pem --key wifiuser.key -
-tls-version tlsv1 -t da16k --insecure
```

3. Sub-Pub#1 (DUT): Write the following command.

```
[/DA16200/NET]# mqtt_config auto 1
[/DA16200/NET]# mqtt_config broker <Broker IP>
[/DA16200/NET]# mqtt_config port <Port Number>
[/DA16200/NET]# mqtt_config sub_topic 1 <Topic>
[/DA16200/NET]# mqtt_config pub_topic <Topic>
[/DA16200/NET]# mqtt_config tls 1
[/DA16200/NET]# sntp enable
[/DA16200/NET]# nvram.setenv dpm_mode 1
[/DA16200/NET]# reboot
```

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```
Connection COMPLETE to 90:9f:33:66:26:52

-- DHCP Client WLAN0: SEL(3)
-- DHCP Client WLAN0: REQ(4)
-- DHCP Client WLAN0: BOUND(5)
        Assigned addr    : 192.168.0.20
              netmask    : 255.255.255.0
              gateway    : 192.168.0.1
              DNS addr   : 210.220.163.82

        DHCP Server IP   : 192.168.0.1
        Lease Time       : 18h 00m 00s
        Renewal Time     : 15h 00m 00s


>>> SNTP Server: pool.ntp.org (106.247.248.106)
>>> SNTP Time sync : 2021.03.11 - 01:29:17
>>> MQTT Client connection OK (da16x_DD12)

>>> Start DPM Power-Down !!!
```

Figure 46: DPM Sleep after MQTT Connection

#Pub (PC): Send the Pub message as below.

>mosquitto_pub -h 192.168.0.101 -p 1884 --cafile cas.pem --cert wifiuser.pem --key wifiuser.key --tls-version tlsv1 -t da16k --insecure -m “Hello World!!”

When the message is received, DA16200/DA16600 wakes up from DPM Sleep and prints the message.

```
Wakeup source is 0x82

>>> TIM STATUS: 0x00000001
>>> TIM : UC
Waking up MCU ...
(Rx: Len=8,Topic=SUB_TOPIC,Msg_ID=0)

>>> Start DPM Power-Down !!!
rwnx_send_set_ps_mod
```

Figure 47: MQTT UC Wakeup

If the code examples are applied, the MQTT publisher starts to post a periodic message every 30 seconds and the MQTT subscriber processes the received PUBLISH messages.

```
Wakeup source is 0x82


(5)rtc_timeout
>>> TIM STATUS: 0x00000010
>>> TIM : FAST
(Tx: Len=26,Topic=PUB_TOPIC,Msg_ID=6)
<< Mqtt Pub EnQ : SUCCESS >>
[PUBREC] (Rx: Msg_ID=6)
[PUBREL] (Tx: Msg_ID=6)
[PUBCOMP] (Rx, Msg_ID=6)

>>> Start DPM Power-Down !!!
```

Figure 48: MQTT Wakeup for Sending Message

11.3.6.1 MQTT Reconnection Scheme

When the broker is disconnected, MQTT Client tries to reconnect to the broker based on the following scheme.

Non-DPM Mode

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1. MQTT Client tries reconnection six times (MQTT_CONN_MAX_RETRY) and is terminated after the max number of trials is reached.

DPM Mode

1. After disconnection from the broker is recognized, the system wakes up from the DPM Sleep, and MQTT Client tries reconnection three times (MQTT_RESTART_MAX_RETRY) and the system enters DPM Sleep when the trials fail.
2. In five seconds, the system wakes up and MQTT Client tries reconnection with the broker. If it fails in connecting to the broker, the system enters the DPM Sleep.
3. "Step 2" is repeated six times (MQTT_CONN_MAX_RETRY) and MQTT Client is terminated after the max number of trials (MQTT_CONN_MAX_RETRY) is reached. The system then enters DPM Sleep.
4. In case other DPM wakeup (User Wakeup, user RTC Wakeup, UC…) happens after "Step 3", "Step 2" is repeated six times.

11.3.6.2 DPM Power Profile

With Keysight, a current consumption measuring tester, check how DPM works in MQTT communication. DPM allows the system to stay in the Sleep mode most of the time and only wake up (and stay active for only a small amount of time to get the job done) when needed.

In the Keysight snapshot below, DA16200/DA16600 was in the Sleep mode until it woke up to post a periodic status message to the broker. Once DA16200/DA16600 received the response, it enters and stays in Sleep mode until the next Status Message Tx time (the interval depends on application).

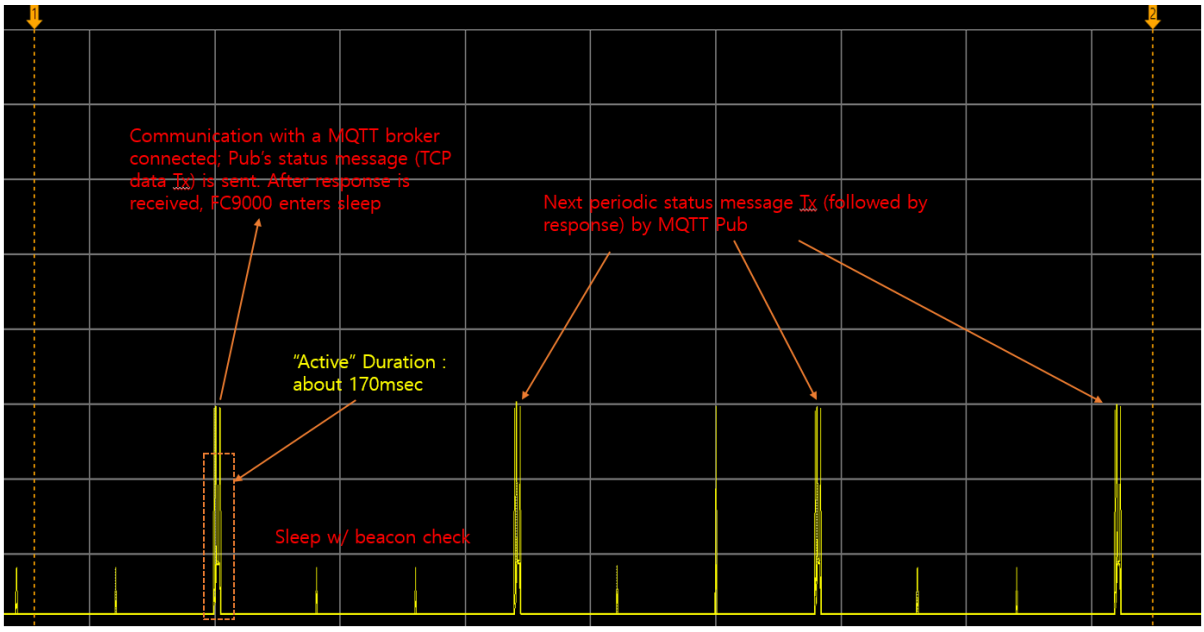

Figure 49: MQTT Communication

11.3.7 MQTT CleanSession=0 Test Guide

11.3.7.1 CleanSession=0 Mode

When an MQTT Client (hereinafter referred to as MQTTC) establishes a connection with an MQTT Broker (Broker onward), there are two types of session: CleanSession=1 and CleanSession=0.

CleanSession=1: default session type. When the Broker receives a connect request from an MQTTC that tries to connect with an option "CleanSession=1" (which is default config on DA16x),

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Broker treats the connection as a “new” session. If an existing session associated with the same client_id is found, the Broker clears that previous session and creates a new one with the client_id.

CleanSession=0: When the Broker receives a connect request from an MQTTC that tries to connect with an option “CleanSession=0”, the Broker first tries to find a session (session data) with the same client_id. If it finds one, it keeps using that session for the new MQTTC.

While Mqttc is connected to the Broker, there may be times when the TCP connection becomes unstable and disconnected (for example, mqtt ping failed). This may cause some messages that had been published to the Broker during that time to not be delivered to a subscriber. If new messages (with QoS > 0) are published to the Broker and for sessions that have been configured in “CleanSession=0”, the Broker retains and re-sends them when the Mqttc is re-connected. Mqttc (if CleanSession=0 is enabled) also should retain the state of the unfinished/unacked messages until reconnection.

```
1647307743: New connection from 192.168.0.2 on port 8883.
1647307743: New client connected from 192.168.0.2 as da16x_D9CC (c1, k60).
1647307743: Sending CONNACK to da16x_D9CC (0, 0)
1647307743: Received SUBSCRIBE from da16x_D9CC
1647307743:     SUB_TOPIC (QoS 2)
1647307743: da16x_D9CC 2 SUB_TOPIC
1647307743: Sending SUBACK to da16x_D9CC
```

Figure 50: Broker Console - CleanSession=1 Connection

```
1647307894: Client da16x_D9CC disconnected.
1647307898: New connection from 192.168.0.2 on port 8883.
1647307898: New client connected from 192.168.0.2 as da16x_D9CC (c0, k60).
1647307898: Sending CONNACK to da16x_D9CC (0, 0)
1647307898: Received SUBSCRIBE from da16x_D9CC
1647307898:     SUB_TOPIC (QoS 2)
1647307898: da16x_D9CC 2 SUB_TOPIC
1647307898: Sending SUBACK to da16x_D9CC
```

Figure 51: Broker Console - CleanSession=0 Connection

Even with CleanSession=0 connection, the Broker does not maintain session data if MQTTC is disconnected in the following cases.

- If a new message is published with QoS 0 after MQTTC is disconnected
- If MQTTC’s connection QoS is 0.

DA16200 and DA16600 support CleanSession=0 mode in the following method.

- “CleanSession=0 feature” is enabled by default in SDK v3.2.3.0 or higher (__MQTT_CLEAN_SESSION_MODE_SUPPORT__).
- If an application uses **QoS 1 or Qos 2 and CleanSession=0**, the message (payload) size (both Tx and Rx) should be pre-decided (because there’s limitation in the dpm user pool size). By default, 100 bytes are defined.

  #define MQTT_MSG_TBL_PRESVD_MAX_PLAYLOAD_LEN 100

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Depending on the application's expected maximum payload size, a different value can be defined.

The DPM User Pool has a limited size (approximately 8K in total) in the system.

First check the available "free" DPM User Pool size using the console command "dpm user_pool", and then calculate the max payload length and message number for the application if needed.

The default configuration (payload_len: 100, max_count: 10)

allocates approximately 1.9 kB of dpm user pool (Check mq_msg_tbl_presvd_t for detail).

Search the following compiler options in config_generic_sdk.h.

```
//max payload length of a preserved message
#define MQTT_MSG_TBL_PRESVD_MAX_PLAYLOAD_LEN        100
// max number of preserved messages
#define MQTT_MSG_TBL_PRESVD_MAX_MSG_CNT             10
```

- The following console command is provided to configure CleanSession mode:

  mqtt_client clean_session <1|0>

CleanSession and QoS Matrix Table for PUBLISH Rx

Table 17: CleanSession and QoS Matrix in Message Rx

Subscriber			Unacked Message Delivery (After MQTT Reconnection)	QoS (Effective Actual)	Publisher Message's QoS
Case	Clean Session	QoS			
1	1	0	X	0	0
2	1	1	X	0	0
3	1	2	X	0	0
4	1	0	X	0	1
5	1	1	X	1	1
6	1	2	X	1	1
7	1	0	X	0	2
8	1	1	X	1	2
9	1	2	X	2	2
10	0	0	X	0	0
11	0	1	X	0	0
12	0	2	X	0	0
13	0	0	X	0	1
14	0	1	O	1	1
15	0	2	O	1	1

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Subscriber			Unacked Message Delivery (After MQTT Reconnection)	QoS (Effective Actual)	Publisher Message's QoS
Case	Clean Session	QoS			
16	0	0	X	0	2
17	0	1	O	1	2
18	0	2	O	2	2

Basically, with CleanSession=1, no unacked message delivery happens when a MQTT reconnect happens (marked as x).

With CleanSession=0, only case 14, 15, 17, and 18 makes message redelivery happen for messages that had been delivered to the Broker while the MQTT was offline (marked as O).

CleanSession and QoS Matrix Table for PUBLISH Tx

Expectation 1	Application assumes "sending message" will fail, and waits until MQTT gets re-connected before retrying.
Behavior 1	Application does message send retry.
Expectation 2	Application assumes "sending message" will resume when MQTT gets re-connected.
Behavior 2	Application waits until message send retry by MQTT is complete.

Table 18: CleanSession and QoS Matrix in Message Tx

Publisher			Expectation if MQTT gets disconnected (while QoS 1/2 message is not fully acked or QoS 0 Send is being sent)	Behavior expected when MQTT Client re-connected
Case	Clean Session	QoS		
1	1	0	Expectation 1	Behavior 1
2	1	1	Expectation 1	Behavior 1
3	1	2	Expectation 1	Behavior 1
4	0	0	Expectation 1	Behavior 1
5	0	1	Expectation 2	Behavior 2
6	0	2	Expectation 2	Behavior 2

When publishing a message from DA16x, application's expectation and action/behavior may be different if CleanSession=0 and QoS 1 or 2 are used in some specific cases.

In normal network condition, there's no difference in message send behavior between CleanSession=0 and CleanSession=1.

In some abnormal cases where QoS 1/2's ACK message (PUBACK, PUBREC, PUBREL, or PUBCOMP) gets lost due to bad network conditions (which can cause a MQTTC re-connection), CleanSession=0 can recover the previous message state and resume communication with the Broker.

However, if CleanSession=1 is used, when MQTTC is disconnected, it can safely re-transmit the message when MQTTC is re-connected. Depending on the use case, either approach (CleanSession=0 or CleanSession=1) can be utilized.

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11.3.7.2 Test Steps

How to connect with CleanSession=0

```
[/DA16200/NET] # mqtt_client stop

[/DA16200/NET] # mqtt_config clean_session 0

[/DA16200/NET] # mqtt_config qos 2

[/DA16200/NET] # mqtt_config status

MQTT Client Information:
  - MQTT Status         : Not Running
  - Broker IP           : 192.168.0.230
  - Port                : 8883
  - Pub. Topic          : PUB_TOPIC
  - Sub. Topic          : SUB_TOPIC
  - QoS Level           : 2
  - TLS                 : Enable
  - Clean Session       : No
  - TLS ALPN            : (None)
  - TLS SNI             : (None)
  - TLS CIPHER SUIT     : (None)
  - Ping Period         : 60
  - TLS Incoming buf    : 4096(bytes)
  - TLS Outgoing buf    : 4096(bytes)
  - TLS Auth mode       : 1
  - User name           : (None)
  - Password            : (None)
  - Client ID           : (default: da16x_D9CC)
  - MQTT VER            : 3.1
[/DA16200/NET] # mqtt_client start

MQTT CleanSession=0 Support Mode enabled.
[/DA16200/NET] # >>> MQTT Client connection OK (da16x_D9CC)
```

To activate "**CleanSession=0 support mode**" in DA16x, QoS should be 1 or 2 and CleanSession option should be set to 0.

If either option (CleanSession and QoS) is not set as above, CleanSession=0 support mode is disabled.

How to restart CleanSession=0 test

If re-testing (fresh new test) with CleanSession=0 mode, the Broker may be needed to "clear the previous session" depending on the previous session type.

The reason is that since an MQTTC connects with CleanSession=0, the Broker does not delete the session data until the MQTTC re-connects with CleanSession=1.

Case 1: Previous session is CleanSession=1 and restart a new CleanSession=0 test

```
[/DA16200/NET] # mqtt_client stop

 [mqtt_subscriber_main] mosquitto_loop_forever exited (rc=17, sock=0, errno=0,
runContinueSub=0)
[mqtt_client] terminated
[/DA16200/NET] # mqtt_config clean_session 0
```

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```
[/DA16200/NET] # mqtt_client start

MQTT CleanSession=0 Support Mode enabled.
[/DA16200/NET] # >>> MQTT Client connection OK (da16x D9CC)
```

Case 2: Previous session is CleanSession=0 and re-test of CleanSession=0.

```
[/DA16200/NET] # mqtt_client stop

 [mqtt_subscriber_main] mosquitto_loop_forever exited (rc=17, sock=0, errno=0,
runContinueSub=0)
[mqtt_client] terminated
[/DA16200/NET] #
[/DA16200/NET] #
[/DA16200/NET] #
[/DA16200/NET] # mqtt_config clean_session 1

[/DA16200/NET] # mqtt_client start

[/DA16200/NET] # >>> MQTT Client connection OK (da16x_D9CC)

[/DA16200/NET] #
[/DA16200/NET] # mqtt_client stop

 [mqtt_subscriber_main] mosquitto_loop_forever exited (rc=17, sock=0, errno=0,
runContinueSub=0)
[mqtt_client] terminated
[/DA16200/NET] #
[/DA16200/NET] #
[/DA16200/NET] # mqtt_config clean_session 0

[/DA16200/NET] # mqtt_client start

MQTT CleanSession=0 Support Mode enabled.
[/DA16200/NET] # >>> MQTT Client connection OK (da16x_D9CC)
```

PUBLISH Rx Test

1) Test Steps

Test steps are as follows under non-DPM and DPM modes.

In non-DPM mode:

- DA16x: connect to Broker
- Publisher: send one or two messages
- DA16x: check if the messages are received.
- DA16x: disconnect from Broker
- Publisher: send one or two messages (let say msg_A)
- DA16x: reconnect to Broker
- DA16x: check if msg_A (sent while DA16x is offline) is received

DPM mode:

- DA16x: connect to Broker. Enter DPM Sleep

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- Publisher: send one or two messages
- DA16x: check if the messages are received.
- DA16x: turn off AP. Wait for the MQTT keep alive period to finish (to make sure Broker recognizes the MQTTC disconnection)
- Publisher: send one or two messages (let say msg_A)
- DA16x: turn on AP. Wait until DA16x is connected to AP
- DA16x: reconnected to AP and check if msg_A (sent while DA16x is offline) is received.

Note:

- Mosquitto broker (Broker), Mosquitto publisher (Publisher), and DA16x (Subscriber) are used for the test.
- message length from publisher should be less than or equal to 100. If longer messages are sent, they may not be restored properly when MQTT is reconnected.

2) Test Steps - Example 1 (non-DPM)

Below are the test steps for case 15 (non-DPM mode).

[DA16x] Connect MQTTC with CleanSession=0 and QoS 2

```
[/DA16200/NET] # mqtt_client stop

 [mqtt_subscriber_main] mosquitto_loop_forever exited (rc=17, sock=0, errno=0,
runContinueSub=0)
[mqtt_client] terminated
[/DA16200/NET] #
[/DA16200/NET] #
[/DA16200/NET] #
[/DA16200/NET] #
[/DA16200/NET] # mqtt_config qos 2

[/DA16200/NET] # mqtt_config clean_session 0

[/DA16200/NET] # mqtt_client start

MQTT CleanSession=0 Support Mode enabled.
[/DA16200/NET] # >>> MQTT Client connection OK (da16x D9CC)
```

[Other Publisher] Publish messages

```
C:\mosquitto>mosquitto_pub -h 192.168.0.230 -p 8883 --cafile cas.pem --cert
wifiuser.pem --key wifiuser.key --tls-version tlsv1 --insecure -q 1 -t SUB_TOPIC -
m "hello_qos_0"

C:\mosquitto>mosquitto_pub -h 192.168.0.230 -p 8883 --cafile cas.pem --cert
wifiuser.pem --key wifiuser.key --tls-version tlsv1 --insecure -q 1 -t SUB_TOPIC -
m "hello_qos_1"
```

[DA16x] check the messages are successfully received

```
[/DA16200/NET] #
[/DA16200/NET] # (Rx: Len=11,Topic=SUB_TOPIC,Msg_ID=1)
[PUBACK] (Tx: Msg_ID=1)
(Rx: Len=11,Topic=SUB_TOPIC,Msg_ID=2)
```

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```
[PUBACK] (Tx: Msg_ID=2)
```

[DA16x] disconnect from Broker

```
[/DA16200/NET] #
[/DA16200/NET] # mqtt_client stop

 [mqtt_subscriber_main] mosquitto_loop_forever exited (rc=17, sock=0, errno=0,
runContinueSub=0)
[mqtt_client] terminated
```

[Other Publisher] publish two messages (while DA16x is in disconnected state)

```
C:\mosquitto>mosquitto_pub -h 192.168.0.230 -p 8883 --cafile cas.pem --cert
wifiuser.pem --key wifiuser.key --tls-version tlsv1 --insecure -q 1 -t SUB_TOPIC -
m "hello_qos_2"

C:\mosquitto>mosquitto_pub -h 192.168.0.230 -p 8883 --cafile cas.pem --cert
wifiuser.pem --key wifiuser.key --tls-version tlsv1 --insecure -q 1 -t SUB_TOPIC -
m "hello_qos_3"
```

[DA16x] re-connects to the Broker and checks if the two messages that had been published while DA16x was in a disconnected state are received successfully.

```
[/DA16200/NET] #
[/DA16200/NET] # mqtt_client start

MQTT CleanSession=0 Support Mode enabled.
[/DA16200/NET] # (Rx: Len=11,Topic=SUB_TOPIC,Msg_ID=3)
[PUBACK] (Tx: Msg_ID=3)
(Rx: Len=11,Topic=SUB_TOPIC,Msg_ID=4)
[PUBACK] (Tx: Msg_ID=4)
>>> MQTT Client connection OK (da16x_D9CC)
```

3) Test Steps - Example 2 (DPM)

Below are the test steps for case 18 (DPM mode). Note that Mosquitto broker and Mosquitto publisher are used for the test.

[DA16x] Connect with CleanSession=0 and QoS 2

```
[/DA16200/NET] # mqtt_config qos 2

[/DA16200/NET] # mqtt_config clean_session 0

[/DA16200/NET] # mqtt_config status

MQTT Client Information:
  - MQTT Status   : Not Running
  - Broker IP          : 192.168.0.230
  - Port               : 8883
  - Pub. Topic         : PUB_TOPIC
  - Sub. Topic         : SUB_TOPIC
  - QoS Level          : 2
  - TLS                : Enable
  - Clean Session      : No
  - TLS ALPN           : (None)
  - TLS SNI            : (None)
```

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```
  - TLS CIPHER SUIT     : (None)
  - Ping Period         : 60
  - TLS Incoming buf    : 4096(bytes)
  - TLS Outgoing buf    : 4096(bytes)
  - TLS Auth mode       : 1
  - User name           : (None)
  - Password            : (None)
  - Client ID           : (default: da16x_D9CC)
  - MQTT VER            : 3.1
[/DA16200/NET] #
[/DA16200/NET] #
[/DA16200/NET] # dpm on
[DP
Wakeup source is 0x0
[dpm_init_retmemory] DPM INIT CONFIGURATION(1)

...

System Mode : Station Only (0)
>>> Start DA16X Supplicant ...
>>> DA16x Supp Ver2.7 - 2020_07
>>> Wi-Fi mode : b/g/n -> b/g (for DPM)
>>> MAC address (sta0) : d4:3d:39:10:d9:cc
...
Connection COMPLETE to 00:11:32:ce:8e:6f

-- DHCP Client WLAN0: SEL(6)
-- DHCP Client WLAN0: REQ(1)
-- DHCP Client WLAN0: CHK(8)
-- DHCP Client WLAN0: BOUND(10)
         Assigned addr   : 192.168.1.195
               netmask   : 255.255.255.0
               gateway   : 192.168.1.1
               DNS addr  : 192.168.1.1

         DHCP Server IP  : 192.168.1.1
         Lease Time      : 24h 00m 00s
         Renewal Time    : 20h 00m 00s

MQTT CleanSession=0 Support Mode enabled.
>>> Hello World #2 ( network dependent application ) !!!
>>> MQTT Client connection OK (da16x_D9CC)
>>> Start DPM Power-Down !!!
```

[Other Publisher] Publish messages

```
C:\mosquitto>mosquitto_pub -h 192.168.0.230 -p 8883 --cafile cas.pem --cert
wifiuser.pem --key wifiuser.key --tls-version tlsv1 --insecure -q 2 -t SUB_TOPIC -
m "hello_qos_1"

C:\mosquitto>mosquitto_pub -h 192.168.0.230 -p 8883 --cafile cas.pem --cert
wifiuser.pem --key wifiuser.key --tls-version tlsv1 --insecure -q 2 -t SUB_TOPIC -
m "hello_qos_2"
```

[DA16x] check the messages are successfully received

```
Wakeup source is 0x82

>>> Start DA16X Supplicant ...
```


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```
>>> TIM STATUS: 0x00000001
>>> TIM : UC
>>> Hello World #1 ( Non network dependent application ) !!!
  MQTT CleanSession=0 Support Mode enabled.
>>> Hello World #2 ( network dependent application ) !!!
(Rx: Len=11,Topic=SUB_TOPIC,Msg_ID=1)
[PUBREC] (Tx: Msg_ID=1)
[PUBREL] (Rx: Msg_ID=1)
[PUBCOMP] (Tx: Msg_ID=1)
>>> Start DPM Power-Down !!!
[i3ed11_dpm_tcp_ack_proc] TCP Update SEQ Ný
Wakeup source is 0x82

>>> Start DA16X Supplicant ...
>>> TIM STATUS: 0x00000001
>>> TIM : UC
>>> Hello World #1 ( Non network dependent application ) !!!
  MQTT CleanSession=0 Support Mode enabled.
>>> Hello World #2 ( network dependent application ) !!!
(Rx: Len=11,Topic=SUB_TOPIC,Msg_ID=2)
[PUBREC] (Tx: Msg_ID=2)
[PUBREL] (Rx: Msg_ID=2)
[PUBCOMP] (Tx: Msg_ID=2)
>>> Start DPM Power-Down !!!
[i3ed11_dpm_tcp_ack_proc] TCP Update SEQ Num(20d7)
PS TIME 130369 us
```

[DA16x] Turn off AP

```
Wakeup source is 0x82

>>> Start DA16X Supplicant ...
>>> TIM STATUS: 0x00000008
>>> TIM : No BCN

>>> Network Interface (wlan0) : DOWN
[wpa_supplicant_event_disassoc] CTRL-EVENT-DISCONNECTED bssid=00:11:32:œ:8e:6f
reason=4 locally_generated=1
Fast scan, freq=2432, num_ssids=1
!!! No selected network !!!
Fast scan, freq=2432, num_ssids=1
>>> Hello World #1 ( Non network dependent application ) !!!
!!! No selected network !!!

### User Call-back : Wi-Fi disconnected ( reason_code = 4 ) ...
Fast scan, freq=2432, num_ssids=1
!!! No selected network !!!
!!! No selected network !!!
!!! No selected network !!!
!!! No selected network !!!
!!! No selected network !!!

rtc_timeout (tid:14)
!!! No selected network !!!
[dpm_timer_process] 'mqtt_sub' is not ready. Callback can't be called. (/14)
>> Abnormal DPM(1) operation after 1 second
...
```

[Broker] make sure MQTTC is disconnected

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```
...
1647318510: Socket error on client da16x_D9CC, disconnecting.
...
```

[Other Publisher] publish two messages (while DA16x is in a disconnected state)

```
C:\mosquitto>mosquitto_pub -h 192.168.0.230 -p 8883 --cafile cas.pem --cert
wifiuser.pem --key wifiuser.key --tls-version tlsv1 --insecure -q 2 -t SUB_TOPIC -
m "hello_qos_3"

C:\mosquitto>mosquitto_pub -h 192.168.0.230 -p 8883 --cafile cas.pem --cert
wifiuser.pem --key wifiuser.key --tls-version tlsv1 --insecure -q 2 -t SUB_TOPIC -
m "hello_qos_4"
```

[DA16x] Turn ON AP

[DA16x] Wait until AP is connected and see whether “hello_qos_3” and “hello_qos_4” are received

```
...
Wakeup source is 0x82


System Mode : Station Only (0)
>>> Start DA16X Supplicant ...
>>> DA16x Supp Ver2.7 - 2020_07
>>> Wi-Fi mode : b/g/n -> b/g (for DPM)
>>> MAC address (sta0) : d4:3d:39:10:d9:cc
>>> sta0 interface add OK
>>> Start STA mode...
>>> Hello World #1 ( Non network dependent application ) !!!

>>> Network Interface (wlan0) : UP
>>> Associated with 00:11:32:ce:8e:6f

Connection COMPLETE to 00:11:32:ce:8e:6f

-- DHCP Client WLAN0: SEL(6)
-- DHCP Client WLAN0: REQ(1)
-- DHCP Client WLAN0: CHK(8)
-- DHCP Client WLAN0: BOUND(10)
         Assigned addr   : 192.168.1.195
               netmask   : 255.255.255.0
               gateway   : 192.168.1.1
               DNS addr  : 192.168.1.1

         DHCP Server IP  : 192.168.1.1
         Lease Time      : 24h 00m 00s
         Renewal Time    : 20h 00m 00s

  MQTT CleanSession=0 Support Mode enabled.
>>> Hello World #2 ( network dependent application ) !!!
(Rx: Len=11,Topic=SUB_TOPIC,Msg_ID=3)
[PUBREC] (Tx: Msg_ID=3)
(Rx: Len=11,Topic=SUB_TOPIC,Msg_ID=4)
[PUBREC] (Tx: Msg_ID=4)
>>> MQTT Client connection OK (da16x_D9CC)
[PUBREL] (Rx: Msg_ID=3)
[PUBCOMP] (Tx: Msg_ID=3)
[PUBREL] (Rx: Msg_ID=4)
```

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```
[PUBCOMP] (Tx: Msg_ID=4)
>>> Start DPM Power-Down !!!
```

PUBLISH Tx Test

1) Test Steps

Test steps are as follows.

- DA16x: connect to Broker
- DA16x: send a messages
- DA16x: check if the message send is successful

NOTE
Message length from DA16x should be less than or equal to 100 for case 5 and 6 configuration. Sending longer messages returns failure. For cases other than case 5 or 6, message length limit is 3K.

2) Test Steps – Example

Below are the test steps for case 5 (non-DPM mode).

```
[/DA16200/NET] # mqtt_config qos 1

[/DA16200/NET] # mqtt_config clean_session 0

[/DA16200/NET] # mqtt_client start

  MQTT CleanSession=0 Support Mode enabled.
[/DA16200/NET] # user cb: on_connect
user cb: on_subscribe
>>> MQTT Client connection OK (da16x_D9CC)

[/DA16200/NET] #
[/DA16200/NET] # mqtt_client -m hello_q1

[/DA16200/NET] # (Tx: Len=8,Topic=PUB_TOPIC,Msg_ID=2)
<< Mqtt Pub EnQ : SUCCESS >>
[PUBACK] (Rx, Msg_ID=2)
user cb: on_publish(mid=2)
```

11.3.8 Reset

The following command clears all MQTT configurations:

```
[/DA16200/NET]# mqtt_config reset
```

11.4 Sample Code

This section explains how to test the MQTT client sample application on the DA16200/DA16600 EVB. It describes how to configure and run MQTT client, and how to send or receive a message using DA16x MQTT APIs.

NOTE
This sample version is available in DA16200/DA16600 SDK v3.2.5.0 or higher.

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11.4.1 Test Environment

Users can use an MQTT broker that is compliant to MQTT Spec 3.1 or 3.1.1 but, for this test, Mosquitto broker, Mosquitto subscriber, and Mosquitto publisher are used, which can be download from the following URL: https://mosquitto.org/files/.

The DA16200/DA16600 contains the MQTT client module (hereinafter referred to as **mqtt_client**) that can work with an MQTT broker.

11.4.2 Setup

1. MQTT Broker (hereinafter referred to as **mqtt_broker**)
   - Open a command prompt and go to the Mosquitto folder.
   - Run the Mosquitto broker (mqtt_broker) with TLS configured.
   - Any MQTT broker can be used but, the Mosquitto broker is used for this test.
     - The following config options are used in the .conf file for the sample (depending on the local environment, other options can be modified. For detail explanation for each option, check default .conf file included in the Mosquitto package:

       >> bind_address, cafile <ca_file>, certfile <cert_file>, keyfile <key_file>, require_certificate yes

       >> If TLS is not used, comment out the following options: cafile, certfile, keyfile, and require_certificate as default

```
C:\mosquitto2>mosquitto -c mosq_tls_mike_sj_home_192.168.0.230.conf -p 8883 -v
1664951182: mosquitto version 1.4.14 (build date 11/07/2017  0:03:18.53) starting

1664951182: Config loaded from mosq_tls_mike_sj_home_192.168.0.230.conf.
1664951182: Opening ipv4 listen socket on port 8883.
```

Figure 52: Mosquitto MQTT Broker

2. MQTT subscriber (hereinafter referred to as **mqtt_sub**)
   - Open a new command prompt and run the Mosquitto subscriber (mqtt_sub) with topic **_da16k**.
   - *Note that mqtt_sub should be connected to mqtt_broker.*

```
C:\mosquitto2>mosquitto_sub -h 192.168.0.230 -p 8883 --cafile cas.pem --cert wifiu
ser.pem --key wifiuser.key --tls-version tlsv1 --insecure -t _da16k -q 0
```

Figure 53: Mosquitto MQTT Subscriber

3. MQTT publisher (hereinafter referred to as **mqtt_pub**)
   - Open a new command prompt and run the Mosquitto publisher (mqtt_pub) with topic **_da16k**.
   - Make sure that the mqtt_sub receive the published message sent by mqtt_pub.

```
C:\mosquitto2>mosquitto_pub -h 192.168.0.230 -p 8883 --cafile cas.pem --cert wifiuser.pem
--key wifiuser.key --tls-version tlsv1 --insecure -q 0 -t da16k2 -m "hello2"
```

Figure 54: Mosquitto MQTT Publisher

4. MQTT Client sample application (hereinafter referred to as **mqtt_app**)

The mqtt_app acts as MQTT publisher and MQTT subscriber, see the next section for more information.

11.4.3 How to Test

1. In the e²studio environment, import a project for the MQTT client sample application as follows:

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```
~/SDK/apps/common/examples/Network/MQTT_Client/projects/da16200
~/SDK/apps/common/examples/Network/MQTT_Client/projects/da16600
```

2. Modify the MQTT broker address, port number, TLS, and cert info for the local environment in the source.

```
#define MQTT_SAMPLE_BROKER_IP        "192.168.0.230"
#define MQTT_SAMPLE_BROKER_PORT      8883
#define MQTT_SAMPLE_TLS              1
...
```

   If TLS is enabled, generate certificate sets. Same certificate sets should be set on the broker side as well to get TLS communication working.

```
static const char *cert_buffer0 = ...
static const char *cert_buffer1 = ...
static const char *cert_buffer2 = ...
...
```

3. (Optional) There are two APIs for sending a message; mqtt_client_send_message() and mqtt_client_send_message_with_qos(). By default, mqtt_client_send_message() is used. If the other APIs should be used, enable USE_MQTT_SEND_WITH_QOS_API in mqtt_client_sample.c.
4. Build the DA16200 SDK (do not download it to the DA16200 EVB yet)
5. DA16200 EVB:
   a. At the [/DA16200] prompt, type factory to do a factory reset:
      i. see Page 19 of UM-WI-056, DA16200 DA16600, FreeRTOS Getting Started Guide
   b. Reboot DA16200 EVB.
6. Download the build image to DA16200 EVB and reboot.
7. DA16200 EVB:
   a. Run setup (to connect to a Wi-Fi router) : see the section “Setup for Station mode” of getting started guide Ref. [4]
      i. Setup as STA.
      ii. SNTP Client enable?: select Yes using the default setting (the Internet should be accessible via a Wi-Fi router).
      iii. Dialog DPM (Dynamic Power Management)?: select No.
8. Rebook DA16200 EVB and connect to a Wi-Fi router, and the **mqtt_app** starts running.

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```
System Mode : Station Only (0)
>>> Start DA16X Supplicant ...
>>> DA16x Supp Ver2.7 - 2022_03
>>> MAC address (sta0) : d4:3d:39:10:d9:cc
>>> sta0 interface add OK
>>> Start STA mode...

>>> Network Interface (wlan0) : UP
>>> Associated with 58:ef:68:63:13:95

Connection COMPLETE to 58:ef:68:63:13:95

-- DHCP Client WLAN0: SEL(6)
-- DHCP Client WLAN0: REQ(1)
-- DHCP Client WLAN0: CHK(8)
-- DHCP Client WLAN0: BOUND(10)
         Assigned addr    : 192.168.1.39
               netmask    : 255.255.255.0
               gateway    : 192.168.1.1
               DNS addr   : 192.168.1.1

         DHCP Server IP   : 192.168.1.1
         Lease Time       : 24h 00m 00s
         Renewal Time     : 12h 00m 00s

[MQTT_SAMPLE] MQTT Configuration is done.
>>> SNTP Server: pool.ntp.org (121.174.142.81)

>>> SNTP Time sync : 2022.10.05 - 06:34:05
>>> MQTT Client connection OK (da16x_D9CC)
[MQTT_SAMPLE] Periodic Publish scheduled.
```

Figure 55: MQTT Client is Ready

11.4.3.1 Test with Non-DPM Mode

1. When the mqtt_app starts for the first time, it configures MQTT client. Once it is configured, find MQTT configuration parameters in NVRAM. See my_app_mqtt_user_config() for more information on configuration.
2. Next the mqtt_app waits for the system to sync the system time with SNTP server which is required for successful TLS session.
3. Then, the mqtt_app starts the mqtt_client.
4. After checking the successful connection of mqtt_client with mqtt_broker, the mqtt_app initializes the app resource within my_app_init() and enters into the main loop to handle various events. See the EVT_ANY.

- **MQTT Publish**

  i. The mqtt_app starts 30-second timer in my_app_init(). Every 30 seconds, the mqtt_app tries to send a periodic message. _my_app_mqtt_pub_send_periodic() is the timer callback that triggers the MQTT publish.

  ii. The mqtt_sub will display the published message from the mqtt_app.

```
(Tx: Len=26,Topic=_da16k,Msg_ID=4)
<< Mqtt Pub EnQ : SUCCESS >>
[PUBREC] (Rx: Msg_ID=4)
[PUBREL] (Tx: Msg_ID=4)
[PUBCOMP] (Rx, Msg_ID=4)
[MQTT_SAMPLE] Sending a periodic message complete.
```

Figure 56: MQTT Publish

- **Receive MQTT Message**

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i. mqtt_pub: publish a message “hello” to the topic **da16k1** and try to publish it to other topics as well. The mqtt_app has subscribed to 3 topics: da16k1, da16k2, and da16k3.

ii. mqtt_app: receive the message “hello.” See the message callback “my_app_mqtt_msg_cb()”

```
(Rx: Len=5,Topic=da16k1,Msg_ID=0)
[MQTT_SAMPLE] Msg Recv: Topic=da16k1, Msg=hello
```

Figure 57: Receive MQTT Message

- **Receive and Reply MQTT Message**

i. mqtt_pub: publish a message **reply_needed** to the topic **da16k1**.

ii. mqtt_app: receive the message and try to publish a message **DA16K status: Not bad ( )** to the topic **_da16k**. The message callback “my_app_mqtt_msg_cb()” upon receipt of **reply_needed**, tries to publish a message to the topic **_da16k**.

iii. mqtt_sub (subscribed to _da16k): display the message received.

```
(Rx: Len=12,Topic=da16k1,Msg_ID=0)
[MQTT_SAMPLE] Msg Recv: Topic=da16k1, Msg=reply_needed
(Tx: Len=26,Topic=_da16k,Msg_ID=10)
<< Mqtt Pub EnQ : SUCCESS >>
[PUBREC] (Rx: Msg_ID=10)
[PUBREL] (Tx: Msg_ID=10)
[PUBCOMP] (Rx, Msg_ID=10)
[MQTT_SAMPLE] Sending a reply message complete.
```

Figure 58: Receive and Reply MQTT Message

- **MQTT Unsubscribe**

i. mqtt_pub: publish a message “unsub:da16k2” to the topic **da16k1**.

ii. mqtt_app: receive the message and try to unsubscribe one of subscribed topics. The message callback “my_app_mqtt_msg_cb()” upon receipt of “unsub:da16k2,” tries to unsubscribe da16k2.

iii. Mqtt_pub: try publishing a message to the **da16k2**. Make sure that the mqtt_app do not receive the message.

```
(Rx: Len=12,Topic=da16k1,Msg_ID=0)
[MQTT_SAMPLE] Msg Recv: Topic=da16k1, Msg=unsub:da16k2
[MQTT_SAMPLE] Topic to unsub = da16k2
[MQTT_SAMPLE] Unsubscribe complete.
```

Figure 59: MQTT Unsubscribe

11.4.3.2 Test with DPM Mode

1. DA16200 EVB: enter the command “dpm on” in the command prompt.
2. DA16200 EVB: reboot automatically with the DPM mode. (by “dpm on”)
3. When the mqtt_app starts for the first time, it configures MQTT client. Once it is configured, find mqtt configuration parameters in NVRAM. See my_app_mqtt_user_config() for more information on configuration.
4. Next the mqtt_app waits for the system to sync the system time with SNTP server which is required for successful TLS session.
5. Then, the mqtt_app starts mqtt_client.
6. After checking the successful connection of mqtt_client with mqtt_broker, the mqtt_app initializes the app resources in my_app_init(), and enter into DPM Sleep.

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```
Connection COMPLETE to 58:ef:68:63:13:95

-- DHCP Client WLAN0: SEL(6)
-- DHCP Client WLAN0: REQ(1)
-- DHCP Client WLAN0: CHK(8)
-- DHCP Client WLAN0: BOUND(10)
        Assigned addr    : 192.168.1.39
              netmask    : 255.255.255.0
              gateway    : 192.168.1.1
              DNS addr   : 192.168.1.1

        DHCP Server IP   : 192.168.1.1
        Lease Time       : 24h 00m 00s
        Renewal Time     : 20h 00m 00s

[MQTT_SAMPLE] MQTT Configuration exists.
>>> SNTP Server: pool.ntp.org (121.174.142.81)

>>> SNTP Time sync : 2022.10.05 - 06:39:54
>>> MQTT Client connection OK (da16x_D9CC)
ümQTT_SAMPLE] Periodic Publish scheduled (RTC).
```

Figure 60: MQTT Client Sample Start-up (in DPM Mode)

- **MQTT Publish**

  i. mqtt_app: register 30-second RTC timer in my_app_init() when the system is in the DPM mode. Every 30 seconds, DA16200 EVB awakes and the mqtt_app tries to send a periodic message. my_app_mqtt_pub_send_periodic() is the RTC timer callback that triggers MQTT publish.

  ii. mqtt_sub: display the published message from the mqtt_app.

  iii. mqtt_app: after publishing the periodic message, enter into DPM Sleep.

```
Wakeup source is 0x82

>>> Start DA16X Supplicant ...
>>> TIM STATUS: 0x00002000
>>> TIM : FULL
(Tx: Len=26,Topic=_da16k,Msg_ID=5)
<< Mqtt Pub EnQ : SUCCESS >>
[PUBREC] (Rx: Msg_ID=5)
[PUBREL] (Tx: Msg_ID=5)
[PUBCOMP] (Rx, Msg_ID=5)
[MQTT_SAMPLE] Sending a periodic message complete.
>>> Start DPM Power-Down !!!
```

Figure 61: Periodic MQTT Publish (in DPM Mode)

- **Receive MQTT Message**

  i. mqtt_pub: publish a message “hello” to the topic **da16k1** and try to publish it to other topics as well. The mqtt_app has subscribed to 3 topics: da16k1, da16k2, and da16k3.

  ii. DA16200 EVB wakes up from DPM Sleep and the mqtt_app will receive and display the message “hello” in the console. See the message callback “my_app_mqtt_msg_cb()”

  iii. After display the message, DA16200 EVB enters into DPM Sleep.

```
Wakeup source is 0x82

>>> Start DA16X Supplicant ...
>>> TIM STATUS: 0x00000001
>>> TIM : UC
(Rx: Len=5,Topic=da16k1,Msg_ID=0)
[MQTT_SAMPLE] Msg Recv: Topic=da16k1, Msg=hello
>>> Start DPM Power-Down !!!
```

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Figure 62: Receive MQTT Message (in DPM Mode)

- **Receive and Reply MQTT Message**

  i. mqtt_pub: publish a message “reply_needed” to the topic **da16k1**.

  ii. DA16200 EVB wakes up from DPM Sleep and the mqtt_app will receive the message and try to publish a message “DA16K status: Not bad ( )” to topic **_da16k**. The message callback “my_app_mqtt_msg_cb()” upon receipt of “reply_needed,” tries to publish a message to topic **_da16k**.

  iii. mqtt_sub (subscribed to _da16k): display the message received.

  iv. After displaying the message, DA16200 EVB enters into DPM Sleep.

```
Wakeup source is 0x82

>>> Start DA16X Supplicant ...
>>> TIM STATUS: 0x00000001
>>> TIM : UC
(Rx: Len=12,Topic=da16k1,Msg_ID=0)
[MQTT_SAMPLE] Msg Recv: Topic=da16k1, Msg=reply_needed
(Tx: Len=26,Topic=_da16k,Msg_ID=7)
<< Mqtt Pub EnQ : SUCCESS >>
[PUBREC] (Rx: Msg_ID=7)
[PUBREL] (Tx: Msg_ID=7)
[PUBCOMP] (Rx, Msg_ID=7)
[MQTT_SAMPLE] Sending a reply message complete.
>>> Start DPM Power-Down !!!
```

Figure 63: MQTT Message Receive and Reply (in DPM Mode)

- **MQTT Unsubscribe**

  i. mqtt_pub: publish a message “unsub:da16k2” to the topic **da16k1**.

  ii. DA16200 EVB wakes up from DPM Sleep and the mqtt_app will receive the message and try to unsubscribe one of subscribed topics. The message callback “my_app_mqtt_msg_cb()”, upon receipt of “unsub:da16k2,” tries to unsubscribe da16k2.

  iii. mqtt_pub: try publishing a message to **da16k2**. Make sure that the mqtt_app do not receive the message.

  iv. After displaying the message, DA16200 EVB enters into DPM Sleep.

```
Wakeup source is 0x82

>>> Start DA16X Supplicant ...
>>> TIM STATUS: 0x00000001
>>> TIM : UC
(Rx: Len=12,Topic=da16k1,Msg_ID=0)
[MQTT_SAMPLE] Msg Recv: Topic=da16k1, Msg=unsub:da16k2
[MQTT_SAMPLE] Topic to unsub = da16k2
[MQTT_SAMPLE] Unsubscribe complete.
>>> Start DPM Power-Down !!!
```

Figure 64: MQTT Unsubscribe Action (in DPM Mode)

11.4.4 Code Walkthrough

The MQTT client sample consists of 2 threads. The main thread is mqtt_client_sample(). The job handling thread is my_app_q_handler().

Each job for sample application is triggered by callbacks

```
void mqtt_client_sample(void * param)
{
…
```

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```
        // register callbacks to mqtt_client
        mqtt_client_set_msg_cb(my_app_mqtt_msg_cb);
        mqtt_client_set_pub_cb(my_app_mqtt_pub_cb);
        mqtt_client_set_conn_cb(my_app_mqtt_conn_cb);
        mqtt_client_set_subscribe_cb(my_app_mqtt_sub_cb);
…
        // mqtt user config in the 1st run.
        my_app_mqtt_user_config();

…
        // wait for SNTP sync
        ret = sntp_wait_sync(10);
…
        // start mqtt_client
        mqtt_client_start();
…
        // wait until mqtt_client is connected to mqtt_broker
        my_app_mqtt_chk_connection(10)
…
        // application init
        ret = my_app_init();
…
        // main event loop
        while (1) {
         …
         events = xEventGroupWaitBits(my_app_event_group,…
         …
         if (events & EVT_PUB_COMPLETE) {
         …
                PRINTF(CYAN_COLOR "[MQTT_SAMPLE] Sending a periodic message complete.
\n" CLEAR_COLOR);
         …
         } else if (events & EVT_PUB_ERROR) {
         …
         } else if (events & EVT_UNSUB_DONE) {
                PRINTF(CYAN_COLOR "[MQTT_SAMPLE] Unsubscribe complete. \n" CLEAR_COLOR);
        …
         } else if (events & EVT_UNSUB_ERR) {
        …
        }
}
```

Periodic mqtt publish is triggered by my_app_mqtt_pub_send_periodic() or _my_app_mqtt_pub_send_periodic() in the DPM mode.

```
static void _my_app_mqtt_pub_send_periodic(TimerHandle_t xTimer)
{
        DA16X_UNUSED_ARG(xTimer);

        BaseType_t ret;

        if (!mqtt_client_is_running() && !is_mqtt_client_thd_alive()) {
         PRINTF(CYAN_COLOR "[MQTT_SAMPLE] Mqtt_client is in terminated state,
terminating my app ... \n" CLEAR_COLOR);

         if ((ret = my_app_send_to_q(NAME_JOB_MY_APP_TERM, NULL, APP_MSG_TERMINATE,
NULL)) != pdPASS ) {
```


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```
            PRINTF(RED_COLOR "[%s] Failed to add a message to Q (%d)\r\n"
CLEAR_COLOR, __func__, ret);
        }

        return;
      } else if (!mqtt_client_is_running() && is_mqtt_client_thd_alive()) {
        PRINTF(CYAN_COLOR "[MQTT_SAMPLE] Mqtt_client may be trying to reconnect ...
canceling the job this time \n" CLEAR_COLOR);
        return;
      }

      if ((ret = my_app_send_to_q(NAME_JOB_MQTT_TX_PERIODIC, &tx_periodic,
APP_MSG_PUBLISH, NULL)) != pdPASS ) {
        PRINTF(RED_COLOR "[%s] Failed to add a message to Q (%d)\r\n" CLEAR_COLOR,
__func__, ret);
      }

      return;
}
```

The mqtt_app receives the message through the message callback “my_app_mqtt_msg_cb(),” which triggers the MQTT publish or MQTT unsubscribe action depending on message contents or types.

```
void my_app_mqtt_msg_cb(const char *buf, int len, const char *topic)
{
      DA16X_UNUSED_ARG(len);

      BaseType_t ret;

      PRINTF(CYAN_COLOR "[MQTT_SAMPLE] Msg Recv: Topic=%s, Msg=%s \n" CLEAR_COLOR,
topic, buf);

      if (strcmp(buf, "reply_needed") == 0) {
        if ((ret = my_app_send_to_q(NAME_JOB_MQTT_TX_REPLY, &tx_reply, APP_MSG_PUBLISH,
NULL)) != pdPASS ) {
            PRINTF(RED_COLOR "[%s] Failed to add a message to Q (%d)\r\n"
CLEAR_COLOR, __func__, ret);
        }
      } else if (strncmp(buf, APP_UNSUB_HDR, 6) == 0) {
        if ((ret = my_app_send_to_q(NAME_JOB_MQTT_UNSUB, NULL, APP_MSG_UNSUB, buf)) !=
pdPASS ) {
            PRINTF(RED_COLOR "[%s] Failed to add a message to Q (%d)\r\n"
CLEAR_COLOR, __func__, ret);
        }
      } else {
        return;
      }
}
```

For each action execution, the thread my_app_q_handler( ) will handle the job when one is submitted to the message queue “my_app_q”.

```
void my_app_q_handler(void* arg)
{
…
      while (1) {
        …
        xStatus = xQueueReceive(my_app_q, &RecvVal, portMAX_DELAY);
```

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```
        …
        if (RecvVal == APP_MSG_PUBLISH) {
                …
                my_app_mqtt_pub_msg( ) // invoke mqtt_client_send_message( )
        } else if (RecvVal == APP_MSG_UNSUB) {
                mqtt_client_unsub_topic( )
                …
      }

}
```

- Cert 2: Client Key


```
-----BEGIN RSA PRIVATE KEY-----
MIIEpQIBAAKCAQEA3KO5EOFtm/3wcNmYEgF1VgQpiVtMmsfCuvNpEYh5QdWieSJv
K0xJLWZTw0FYaDt1K/iI/WPLpA9x6gjGveU9Wty8vZYQyDBP1UakYGURmvxQv45I
ivbvUoCFz2aiZNbPyVRu2u3XgvAbyoqiBYV6B5dDeJyccFQPJGoOPHV2608azh9u
gvasFPOYkv3NaMxyTJqtOdlj0kGSCEqvPlZsZQm218UO5FNqGZMQ6lt4TCNzj0vN
LPKuLTM7orb8xTtCbwB4IeCBchO8oJyBO/pTPX9xMMxAsPZxAXS+wL352C4ZSBCP
EvMGU1KZ3fFwOULO0GuKyzbqiNu92SFiS4fb/wIDAQABAoIBAQDcnbCc2mt5AM98
Z3aQ+nhSy9Kkj2/njDqAKIc0ituEIpNUwEOcbaj2Bk1W/W3iuyEMGHURuMmUgAUN
WD0w/5j705+9ieG56eTJgts1r5mM+SHch+6tVQAz5GLn4N4cKlaWHyDBM/S77k47
lacwEijUkkFaxm3+O27woEMf3OxNl24KmRenMYBhqcsoT4BYBw3Bh8xe+XN95rXj
2BdIbr5+RWGc9Zsz4o5Wmd4mL/JvbKeohrsecien4TZRzWFku93XV5kie1c1aJy1
nJ85bGJk4focmP/2ToxQysTbPYCxHVTIHuADK/qf9SGHJ9F7EBHE7+0isuwBbqOD
OzS8rHdRAoGBAPCXlaHumEkLIRv3enhpHPBYxnDndNCtT1T6+Cuit/vfo6K6oA7p
iUaej/GPZsDKXhayeTiEaq7QMinUtGkiCgGlVtXghXuCZz6KrH19W6wzC6Pbokmq
BZak4LQcvGavt3VzjliAKLcdn6nQt/+bp/jKDJOKVbvb30sjS035Ah4zAoGBAOrF
BgE9UTEnfQHIh7pyiM1DAomBbdrlRos8maQl26cHqUHN3+wy1bGHLzOjYFFoAasx
eizw7Gudgbae28WIP1yLGrpt15cqVAvlCYmBtZ3C98FuT3FYgEEZpWNmE8Om+5UM
td+mtMjonWAPkCYC+alqUZzeIs+CZs5CHKYCDqcFAoGBAOfkQv38GV2102jARJPQ
RGtINaRXApmrod43s4Fjac/kAzVyiZk18PFXHUhnvlMt+jgIN5yIzMbHtsHo2SbH
/zsM4MBuklm0G80FHjIp5HT6EksSA77amF5VdptDYzfaP4p+IYIdrKCqddzYZrCA
mArMvAhs+iuCRhuG3is+SZNPAoGAHs6r8w2w0dp0tP8zkGvnN8hLVO//EnJzx2G0
Z63wHQMMWu5BLCWflSRANW6C/SvAzE450hvralPI6cX+4PT4G5TFdSFk4RlU3hq4
Has/wewLxv5Kvnz2l5Rd96U1gr8u1GhOlYKyxop/3FMuf050pJ6nBwa/WquqAfb6
+23ZrmECgYEA6l0GFHwMFBNnpPuxHgYgS5+4g3+8DhZZIDc7IflBCBWF/ZwbM+nH
+JSxiYYjvD7zIBhndqERcZ+fvbZTQ8oymr3j5AESM0ZfAHbft6IFQWjDUC3IDUF/
4F0cUidFC8smu6Wa2tjvSIz7DfvmDsn1l+7s9qQvDxdyPas0IkL/v8w=
-----END RSA PRIVATE KEY-----
```


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12 Network Examples: Protocols/Applications

12.1 CoAP Client

12.1.1 Peer Application

The example in this section requires a peer device (Laptop) running a CoAP test server application to demonstrate the DA16200 CoAP client sample application. The sample application is based on Eclipse Californium (https://www.eclipse.org/californium/) and runs on a Windows OS as shown in Figure 65.

```
C:\Samples>coap_server.exe
*****************************************************************
* CoAP Server
* ver. 1.0
* resources
*        \res
*        \obs_res
*****************************************************************
```

Figure 65: Start of CoAP Server Application

The CoAP server application is a simple CoAP server. It has two resources, called \res and \obs_res. The "res" resource allows GET, POST, PUT, DELETE, and PING methods. The "obs_res" resource allows OBSERVE request to send an observe notification every ten seconds.

12.1.2 How to Run

1. Run a CoAP server application on the peer PC.
2. In the e²studio, import a project for the CoAP Client application as follows:
   - *~/SDK/apps/common/examples/Network/CoAP_Client/projects/da16200*
3. Build the DA16200 SDK, download the RTOS image to the DA16200 EVB, and reboot.
4. Use the console command to set up the Wi-Fi station interface.

After a connection is made to an AP, the example application initializes a CoAP client to start the service.

12.1.3 CoAP Client Initialization

This section explains how to initialize and construct a CoAP client.

```
int coap_client_sample_init_config(coap_client_sample_conf_t *config)
{
      int ret = DA_APP_SUCCESS;

      coap_client_t *coap_client_ptr = &config->coap_client;

      config->state = COAP_CLIENT_SAMPLE_STATE_SUSPEND;

      //Init coap client
      ret = coap_client_init(coap_client_ptr, COAP_CLIENT_SAMPLE_DEF_NAME);
      if (ret != DA_APP_SUCCESS) {
          PRINTF("[%s]Failed to init coap client(0x%x)\r\n", __func__, -ret);
          goto end;
      }

      coaps_client_set_authmode(coap_client_ptr, 0);

      config->req_port = COAP_CLIENT_SAMPLE_REQUEST_PORT;
      config->obs_port = COAP_CLIENT_SAMPLE_OBSERVE_PORT;
```

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```
end:

      return ret;
}
```

The coap_client_sample_init_config function guides how the CoAP client is initialized. The coap_client_init function initializes the CoAP Client instance. If a CoAP observe relationship is already established in DPM wakeup, It will be recovered. The API's details are as follows:

Table 19: APIs for Initializing CoAP Client

Item	Description
int coap_client_init(coap_client_t *client_ptr, char *name_ptr)	
Prototype	int coap_client_init(coap_client_t *client_ptr, char *name_ptr)
Parameter	client_ptr: CoAP Client instance pointer name_ptr: Name of CoAP Client
Return	0 (NX_SUCCESS) on success
Description	Initialize CoAP Client.
int coaps_client_set_authmode(coap_client_t *client_ptr, unsigned int mode)	
Prototype	int coaps_client_set_authmode(coap_client_t *client_ptr, unsigned int mode)
Parameter	client_ptr: CoAP Client instance pointer mode: DTLS's auth mode
Return	0(NX_SUCCESS) on success
Description	If true, DTLS Server's certificate validity will be checked during DTLS handshake. Default is false.

12.1.4 CoAP Client Deinitialization

This section explains how to release the CoAP client.

```
int coap_client_sample_deinit_config(coap_client_sample_conf_t *config)
{
      int ret = DA_APP_SUCCESS;
      coap_client_t *coap_client_ptr = &config->coap_client;

      //Deinit coap client
      ret = coap_client_deinit(coap_client_ptr);
      if (ret != DA_APP_SUCCESS) {
          PRINTF("[%s]Failed to deinit coap client(0x%x)\r\n", __func__, -ret);
      }

      return ret;
}
```

The coap_client_deinit function releases the CoAP client. The API details are as follows.

Table 20: API for Deinitializing CoAP Client

Item	Description
int coap_client_deinit(coap_client_t *client_ptr)	
Prototype	int coap_client_deinit(coap_client_t *client_ptr)
Parameter	client_ptr: CoAP Client instance pointer
Return	0(NX_SUCCESS) on success

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Item	Description
int coap_client_deinit(coap_client_t *client_ptr)	
Description	Deinitialize CoAP Client.

12.1.5 CoAP Client Request and Response

The DA16200 provides a CoAP client request (GET/POST/PUT/DELETE/PING) and response. In this section, we describe how the DA16200 sends the CoAP request to the CoAP server and receives the CoAP response.

12.1.5.1 CoAP URI and Proxy URI

To transmit a CoAP request and response, a URI must be set up. DA16200 provides APIs as shown below.

Table 21: APIs for Setting Up CoAP URI and Proxy URI

Item	Description
int coap_client_set_uri(coap_client_t *client_ptr, unsigned char *uri, size_t urilen)	
Prototype	int coap_client_set_uri(coap_client_t *client_ptr, unsigned char *uri,size_t urilen)
Parameter	client_ptr: CoAP Client instance pointer uri: URI of CoAP request urilen: Length of URI
Return	0(NX_SUCCESS) on success
Description	Setup URI.
int coap_client_set_proxy_uri(coap_client_t *client_ptr, unsigned char *uri, size_t urilen)	
Prototype	int coap_client_set_proxy_uri(coap_client_t *client_ptr, unsigned char *uri, size_t urilen)
Parameter	client_ptr: CoAP Client instance pointer uri: Proxy URI of CoAP request urilen: Length of URI
Return	0(NX_SUCCESS) on success
Description	Setup Proxy URI. If URI is NULL, previous Proxy URI is removed

12.1.5.2 GET Method

The DA16200 provides an API to send a GET request as shown in the example code.

```
int coap_client_sample_request_get(coap_client_sample_conf_t *config,
                                   coap_client_sample_request_t *request)
{
      int ret = DA_APP_SUCCESS;
      coap_client_t *coap_client_ptr = &config->coap_client;
      coap_rw_packet_t resp_packet;
      memset(&resp_packet, 0x00, sizeof(coap_rw_packet_t));

      //set URI.
      ret = coap_client_set_uri(coap_client_ptr,
                                (unsigned char *)request->uri,
                                 request->urilen);
```

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```
        //set Proxy URI. If null, previous proxy uri will be removed.
        ret = coap_client_set_proxy_uri(coap_client_ptr,
                                        (unsigned char *)request->proxy_uri,
                                         request->proxy_urilen);

        //send coap request
        ret = coap_client_request_get_with_port(coap_client_ptr, config->req_port);

        //receive coap response
        ret = coap_client_recv_response(coap_client_ptr, &resp_packet);

        //display output
        if (resp_packet.payload.len) {
         coap_client_sample_hexdump("GET Request",
                                    resp_packet.payload.p,
                                    resp_packet.payload.len);
        }

 end:
        //release coap response
        coap_clear_rw_packet(&resp_packet);

        return ret;
 }
```

The CoAP GET request is generated and sent in function coap_client_request_get_with_port(). A CoAP response is received in function coap_client_recv_response(). The API details are as follows:

Table 22: GET API for CoAP Client

Item	Description
int coap_client_request_get_with_port(coap_client_t *client_ptr, unsigned int port)	
Prototype	int coap_client_request_get_with_port(coap_client_t *client_ptr, unsigned int port)
Parameter	client_ptr: CoAP Client instance pointer port: UDP socket's local port number
Return	0(NX_SUCCESS) on success
Description	CoAP Client sends GET request

The DA16200 CoAP client sample application provides a command to send a GET request to the CoAP server. Figure 66, Figure 67, and Figure 68 show the interaction of two DA16200 CoAP clients with the CoAP server for a GET request.

```
[/DA16200] # user.coap_client -get coap://192.168.0.11/res
Operation code       : GET       (1)
URI                  : coap://192.168.0.11/res(24)
[/DA16200/user] # ===== GET Request(len:18) =====
0000: 53 61 6D 70 6C 65 20 43 6F 41 50 20 53 65 72 76   Sample CoAP Serv
0010: 65 72                                             er
```

Figure 66: GET Method of CoAP Client #1

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```
C:\Samples>coap_server
*****************************************************************
* CoAP Server
* ver. 1.0
* resources
*        \res
*        \obs_res
*****************************************************************

Received GET request
```

Figure 67: GET Method of CoAP Client #2

Source	Destination	Protocol	length	src port	dst port	Information
192.168.0.2	192.168.0.11	CoAP	61	10200	5683	CON, MID:1, GET, TKN:69 a1 d9 0f 04 d6 3d 52, End of Block #0, /res
192.168.0.11	192.168.0.2	CoAP	74	5683	10200	ACK, MID:1, 2.05 Content, TKN:69 a1 d9 0f 04 d6 3d 52, /res (text/plain)

Figure 68: GET Method of CoAP Client #3

12.1.5.3 POST Method

DA16200 provides an API to send a POST request as shown in the example code.

```
int coap_client_sample_request_post(coap_client_sample_conf_t *config,
                                    coap_client_sample_request_t *request)
{
      int ret = DA_APP_SUCCESS;
      coap_client_t *coap_client_ptr = &config->coap_client;
      coap_rw_packet_t resp_packet;
      memset(&resp_packet, 0x00, sizeof(coap_rw_packet_t));

      //set URI
      ret = coap_client_set_uri(coap_client_ptr,
                                (unsigned char *)request->uri,
                                 request->urilen);

      //set Proxy URI. If null, previous proxy uri will be removed.
      ret = coap_client_set_proxy_uri(coap_client_ptr,
                                      (unsigned char *)request->proxy_uri,
                                       request->proxy_urilen);

      //send coap request
      ret = coap_client_request_post_with_port(coap_client_ptr, config->req_port,
                                               request->data, request->datalen);

      //receive coap response
      ret = coap_client_recv_response(coap_client_ptr, &resp_packet);

      //display output
      if (resp_packet.payload.len) {
          coap_client_sample_hexdump("POST Request",
                                      resp_packet.payload.p,
                                      resp_packet.payload.len);
      }

end:
      //release coap response
      coap_clear_rw_packet(&resp_packet);
      return ret;
}
```

A CoAP POST request is generated and sent in function coap_client_request_post_with_port(). A CoAP response is received in function coap_client_recv_response(). The API details are as follows.

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Table 23: POST API for CoAP Client

Item	Description
UINT coap_client_request_post_with_port(coap_client_t *client_ptr, UINT port, unsigned char * payload, unsigned int payload_len)	
Prototype	UINT coap_client_request_post_with_port(coap_client_t *client_ptr, UINT port, unsigned char *payload, unsigned int payload_len)
Parameter	client_ptr: CoAP Client instance pointer port: UDP socket's local port number payload: Payload pointer payload_len: Length of payload
Return	0 (NX_SUCCESS) on success
Description	CoAP Client sends POST request

The DA16200 CoAP client sample application has a command to send a POST request to a CoAP server. Figure 69, Figure 70, and Figure 71 show the interaction of two DA16200 CoAP clients with the CoAP server for a POST request.

```
[/DA16200] # user.coap_client -post 123 coap://192.168.0.11/res
Operation code      : POST      (3)
URI                 : coap://192.168.0.11/res(24)
PAYLOAD             : 123(4)
[/DA16200/user] # ===== POST Request(len:4) =====
0000: 31 32 33 00                                          123.
```

Figure 69: POST Method of CoAP Client #1

```
C:\Samples>coap_server
*****************************************************************
* CoAP Server
* ver. 1.0
* resources
*        \res
*        \obs_res
*****************************************************************

Received POST request
```

Figure 70: POST Method of CoAP Client #2

Source	Destination	Protocol	length	src port	dst port	Information
192.168.0.2	192.168.0.11	CoAP	64	10200	5683	CON, MID:1, POST, TKN:e9 e5 f0 26 4d f6 95 25, /res (text/plain)
192.168.0.11	192.168.0.2	CoAP	60	5683	10200	ACK, MID:1, 2.04 Changed, TKN:e9 e5 f0 26 4d f6 95 25, /res (text/plain)

Figure 71: POST Method of CoAP Client #3

12.1.5.4 PUT Method

DA16200 provides an API to send a PUT request as shown in the example code.

```
int coap_client_sample_request_put(coap_client_sample_conf_t *config,
                                   coap_client_sample_request_t *request)
{
      int ret = DA_APP_SUCCESS;
      coap_client_t *coap_client_ptr = &config->coap_client;
      coap_rw_packet_t resp_packet;

      memset(&resp_packet, 0x00, sizeof(coap_rw_packet_t));

      //set URI
      ret = coap_client_set_uri(coap_client_ptr,
                                (unsigned char *)request->uri,
                                 request->urilen);
```

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```
        //set Proxy URI. If null, previous proxy uri will be removed.
        ret = coap_client_set_proxy_uri(coap_client_ptr,
                                        (unsigned char *)request->proxy_uri,
                                         request->proxy_urilen);


        //send coap request
        ret = coap_client_request_put_with_port(coap_client_ptr, config->req_port,
                                                request->data,
                                                request->datalen);

        //receive coap response
        ret = coap_client_recv_response(coap_client_ptr, &resp_packet);

        //display output
        if (resp_packet.payload.len) {
         coap_client_sample_hexdump("PUT Request",
                                    resp_packet.payload.p,
                                    resp_packet.payload.len);
        }

 end:
        //release coap response
        coap_clear_rw_packet(&resp_packet);

        return ret;
 }
```

The CoAP PUT request is generated and sent in function coap_client_request_put_with_port(). A CoAP response is received in function coap_client_recv_response(). The API details are as follows.

Table 24: PUT API for CoAP Client

Item	Description
int coap_client_request_put_with_port(coap_client_t *client_ptr, unsigned int port, unsigned char *payload, unsigned int payload_len)	
Prototype	int coap_client_request_put_with_port(coap_client_t *client_ptr, unsigned int port, unsigned char *payload, unsigned int payload_len)
Parameter	client_ptr: CoAP Client instance pointer port: UDP socket's local port number payload: Payload pointer payload_len: Length of payload
Return	0(NX_SUCCESS) on success
Description	CoAP Client sends PUT request

The DA16200 CoAP client sample application provides a command to send a PUT request to the CoAP server. Figure 72, Figure 73, and Figure 74 show the interaction of two DA16200 CoAP clients and the CoAP server for PUT requests.

```
[/DA16200] # user.coap_client -put 123 coap://192.168.0.11/res
Operation code      : PUT       (2)
URI                 : coap://192.168.0.11/res(24)
PAYLOAD             : 123(4)
```

Figure 72: PUT Method of CoAP Client #1

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```
C:\Samples>coap_server
*****************************************************************
* CoAP Server
* ver. 1.0
* resources
*       \res
*       \obs_res
*****************************************************************

Received PUT request
```

Figure 73: PUT Method of CoAP Client #2

Source	Destination	Protocol	length	src port	dst port	Information
192.168.0.2	192.168.0.11	CoAP	64	10200	5683	CON, MID:1, POST, TKN:7e 7a e6 c2 ae aa 16 93, /res (text/plain)
192.168.0.11	192.168.0.2	CoAP	60	5683	10200	ACK, MID:1, 2.04 Changed, TKN:7e 7a e6 c2 ae aa 16 93, /res (text/plain)

Figure 74: PUT Method of CoAP Client #3

12.1.5.5 DELETE Method

DA16200 provides an API to send a DELETE request as shown in the example code.

```
int coap_client_sample_request_delete(coap_client_sample_conf_t *config,
                                      coap_client_sample_request_t *request)
{
      int ret = DA_APP_SUCCESS;
      coap_client_t *coap_client_ptr = &config->coap_client;
      coap_rw_packet_t resp_packet;
      memset(&resp_packet, 0x00, sizeof(coap_rw_packet_t));

      //set URI
      ret = coap_client_set_uri(coap_client_ptr,
                                (unsigned char *)request->uri,
                                request->urilen);

      //set Proxy URI. If null, previous proxy uri will be removed.
      ret = coap_client_set_proxy_uri(coap_client_ptr,
                                      (unsigned char *)request->proxy_uri,
                                      request->proxy_urilen);

      //send coap request
      ret = coap_client_request_delete_with_port(coap_client_ptr, config->req_port);

      //receive coap response
      ret = coap_client_recv_response(coap_client_ptr, &resp_packet);

      //display output
      if (resp_packet.payload.len) {
       coap_client_sample_hexdump("DELETE Request",
                                  resp_packet.payload.p,
                                  resp_packet.payload.len);
      }

end:
      //release coap response
      coap_clear_rw_packet(&resp_packet);

      return ret;
}
```

A CoAP DELETE request is generated and sent in function coap_client_request_delete_with_port(). A CoAP response is received in function coap_client_recv_response(). The API details are as follows.

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Table 25: DELETE API for CoAP Client

Item	Description
int coap_client_request_delete_with_port(coap_client_t *client_ptr, unsigned int port)	
Prototype	int coap_client_request_delete_with_port(coap_client_t *client_ptr, unsigned int port)
Parameter	client_ptr: CoAP Client instance pointer port: UDP socket's local port number
Return	0(NX_SUCCESS) on success
Description	CoAP Client sends DELETE request to the URI

DA16200 CoAP client sample application provides a command to send a DELETE request to the CoAP server. Figure 75, Figure 76, and Figure 77 show the interaction of a DA16200 CoAP client and the CoAP server for a DELETE request.

```
[/DA16200] # user.coap_client -delete coap://192.168.0.11/res
Operation code       : DELETE    (4)
URI                  : coap://192.168.0.11/res(24)
```

Figure 75: DELETE Method of CoAP Client #1

```
C:\Samples>coap_server
*****************************************************************
* CoAP Server
* ver. 1.0
* resources
*        \res
*        \obs_res
*****************************************************************

Received DELETE request
```

Figure 76: DELETE Method of CoAP Client #2

Source	Destination	Protocol	length	src port	dst port	Information
192.168.0.2	192.168.0.11	CoAP	60	10200	5683	CON, MID:1, DELETE, TKN:51 6c db 10 c9 08 c5 93, /res
192.168.0.11	192.168.0.2	CoAP	54	5683	10200	ACK, MID:1, 2.02 Deleted, TKN:63 28 6b c4 4b dc 67 e3

Figure 77: DELETE Method of CoAP Client #3

12.1.5.6 CoAP Ping

DA16200 provides an API to send a PING request as shown in the example code.

```
int coap_client_sample_request_ping(coap_client_sample_conf_t *config,
                                    coap_client_sample_request_t *request)
{
      int ret = DA_APP_SUCCESS;
      coap_client_t *coap_client_ptr = &config->coap_client;

      //set URI
      ret = coap_client_set_uri(coap_client_ptr,
                                (unsigned char *)request->uri,
                                 request->urilen);

      //set Proxy URI. If null, previous proxy uri will be removed.
      ret = coap_client_set_proxy_uri(coap_client_ptr,
                                      (unsigned char *)request->proxy_uri,
                                       request->proxy_urilen);

      //progress ping request
      ret = coap_client_ping_with_port(coap_client_ptr, config->req_port);
```

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```
end:

        return ret;
}
```

A CoAP PING request is processed in function coap_client_ping_with_port(). The API details are as follows.

Table 26: PING API for CoAP Client

Item	Description
int coap_client_ping_with_port(coap_client_t *client_ptr, unsigned int port)	
Prototype	int coap_client_ping_with_port(coap_client_t *client_ptr, unsigned int port)
Parameter	client_ptr: CoAP Client instance pointer port: UDP socket's local port number
Return	0(NX_SUCCESS) on success
Description	CoAP Client sends PING request

The DA16200 CoAP client sample application has a command to send a PING method to the CoAP server. Figure 78 and Figure 79 show the interaction of the DA16200 CoAP client and the CoAP server for a PING request.

```
[/DA16200] # user.coap_client -ping coap://192.168.0.11/res
Operation code      : PING      (7)
URI                 : coap://192.168.0.11/res(24)
```

Figure 78: PING Method of CoAP Client #1

Source	Destination	Protocol	length	src port	dst port	Information
192.168.0.2	192.168.0.11	CoAP	60	10200	5683	CON, MID:3, Empty Message, TKN:7e 7a e6 c2 ae aa 16 95, /res
192.168.0.11	192.168.0.2	CoAP	46	5683	10200	RST, MID:3, Empty Message

Figure 79: PING Method of CoAP Client #2

12.1.5.7 CoAP Response

DA16200 constructs a CoAP response in coap_rw_packet_t structure. In this section, details are given of how a CoAP response is constructed.

```
~/SDK/core/coap/coap_common.h

  typedef struct {
      /// Version number
      uint8_t version;
      /// Message type
      uint8_t type;
      /// Token length
      uint8_t token_len;
      /// Status code
      uint8_t code;
      /// Message-ID
      uint8_t msg_id[2];
  } coap_header_t;

  typedef struct {
      /// Option number
      uint8_t num;
      /// Option value
```

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```
    coap_rw_buffer_t buf;
} coap_rw_option_t;

typedef struct {
    /// Header of the packet
    coap_header_t header;
    /// Token value, size as specified by header.token_len
    coap_rw_buffer_t token;
    /// Number of options
    uint8_t numopts;
    /// Options of the packet
    coap_rw_option_t opts[MAXOPT];
    /// Payload carried by the packet
    coap_rw_buffer_t payload;
} coap_rw_packet_t;
```

The coap_rw_packet_t structure includes the CoAP response information. After CoAP response is received, DA16200 parses and constructs it. To receive a CoAP response, DA16200 provides an API. See Table 27. The API must be called after a CoAP requests to send a response.

Table 27: Response APIs for CoAP Client

Item	Description
void coap_clear_rw_packet(coap_rw_packet_t *packet)	
Prototype	void coap_clear_rw_packet(coap_rw_packet_t *packet)
Parameter	client_ptr: CoAP Client instance pointer resp_ptr: CoAP response
Return	0 (NX_SUCCESS) on success
Description	Release coap_rw_packet structure
int coap_client_recv_response(coap_client_t *client_ptr, coap_rw_packet_t *resp_ptr)	
Prototype	int coap_client_recv_response(coap_client_t *client_ptr, coap_rw_packet_t *resp_ptr)
Parameter	client_ptr: CoAP Client instance pointer resp_ptr: CoAP response
Return	0(NX_SUCCESS) on success
Description	Receive CoAP response for specific CoAP request

To receive a CoAP response, DA16200 provides an API that is mentioned below. The API must be called after a CoAP requests to send a response.

12.1.6 CoAP Observe

This section describes how CoAP observe is registered and deregistered from the CoAP server. DA16200 provides a CoAP observe functionality. After registration at a CoAP server, DA16200 (CoAP client) is ready to receive an observe notification.

12.1.6.1 Registration

DA16200 provides an API to register a CoAP observe as shown in the example code.

```
int coap_client_sample_register_observe(coap_client_sample_conf_t *config,
                                        coap_client_sample_request_t *request)
{
    int ret = DA_APP_SUCCESS;
    coap_client_t *coap_client_ptr = &config->coap_client;

    //set URI
    ret = coap_client_set_uri(coap_client_ptr,
```

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```
                                (unsigned char *)request->uri,
                                 request->urilen);

        //set Proxy URI. If null, previous proxy uri will be removed.
        ret = coap_client_set_proxy_uri(coap_client_ptr,
                                        (unsigned char *)request->proxy_uri,
                                         request->proxy_urilen);

        //register coap observe
        ret = coap_client_set_observe_notify_with_port(coap_client_ptr,
                                            config->obs_port,
                                            coap_client_sample_observe_notify,
                                            coap_client_sample_observe_close_notify);

end:

        return ret;
}
```

A DA16200 CoAP observe allows only one connection. After successful registration, a DA16200 CoAP client allows receiving an observe notification. When the observe notification is received, the callback function (observe_notify) is called. If there is no observe notification during the max-age, the close callback function (observe_close_notify) is called. The API details are as follows.

Table 28: Observe Registration API for CoAP Client

Item	Description
int coap_client_set_observe_notify_with_port(coap_client_t *client_ptr, unsigned int port, int (*observe_notify)(void *client_ptr, coap_rw_packet_t *resp_ptr), void (*observe_close_notify)(char *timer_name))	
Prototype	int coap_client_set_observe_notify_with_port(coap_client_t *client_ptr, unsigned int port, int (*observe_notify)(void *client_ptr, coap_rw_packet_t *resp_ptr), void (*observe_close_notify) (char *timer_name))
Parameter	client_ptr: CoAP Client instance pointer port: UDP socket's local port number observe_notify: Callback function for CoAP observe notification observe_close_notify: Callback function for CoAP observe closing
Return	0(NX_SUCCESS) on success
Description	Register CoAP observe. The callback function, observe_notify, will be called when CoAP observe notification is received

The DA16200 CoAP client sample application has a command for CoAP observe. Figure 80, Figure 81, and Figure 82 show the interaction of a DA16200 CoAP client and the CoAP server for CoAP observe. The CoAP server sends an observe notification every five seconds before deregistration.

```
[/DA16200] # user.coap_client -reg_observe coap://192.168.0.11/obs_res
Operation code       : REG_OBSERVE(5)
URI                  : coap://192.168.0.11/obs_res(28)
[/DA16200/user] # [coap_client_sample_observe_notify]Received Observe notification(25)
===== Observe Notification(len:25) =====
0000: 43 6F 41 50 20 4F 62 73 65 72 76 65 20 4E 6F 74   CoAP Observe Not
0010: 69 66 69 63 61 74 69 6F 6E                        ification
```

Figure 80: CoAP Observe of CoAP Client #1

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```
C:\Samples>coap_server
*****************************************************************
* CoAP Server
* ver. 1.0
* resources
*        \res
*        \obs_res
*****************************************************************

Send Observe notification
Send Observe notification
```

Figure 81: CoAP Observe of CoAP Client #2

Source	Destination	Protocol	length	src port	dst port	Information
192.168.0.2	192.168.0.11	CoAP	67	10201	5683	CON, MID:1, GET, TKN:fc 48 1b 0b 13 e7 b1 02, End of Block #0, /obs_res
192.168.0.11	192.168.0.2	CoAP	84	5683	10201	ACK, MID:1, 2.05 Content, TKN:fc 48 1b 0b 13 e7 b1 02, /obs_res (text/plain)
192.168.0.11	192.168.0.2	CoAP	85	5683	10201	CON, MID:46584, 2.05 Content, TKN:fc 48 1b 0b 13 e7 b1 02, /obs_res (text/plain)
192.168.0.2	192.168.0.11	CoAP	60	10201	5683	ACK, MID:46584, Empty Message

Observe nofitication

Figure 82: CoAP Observe of CoAP Client #3

12.1.6.2 Deregistration

DA16200 provides an API to deregister a CoAP observe as shown in the example code.

```
int coap_client_sample_unregister_observe(coap_client_sample_conf_t *config)
{
        int ret = DA_APP_SUCCESS;
        coap_client_t *coap_client_ptr = &config->coap_client;
        coap_client_clear_observe(coap_client_ptr);

        return ret;
}
```

The API details are as follows.

Table 29: Observe Deregistration API for CoAP Client

Item	Description
VOID coap_client_clear_observe(coap_client_t*coap_client)	
Prototype	VOID coap_client_clear_observe(coap_client_t*coap_client)
Parameter	coap_client: CoAP Client instance pointer
Return	-
Description	Deregister CoAP observe relation

12.2 DNS Query

12.2.1 How to Run

This section shows how to get the IPv4 address from a domain name URL. Two types of API functions are supported to get the IP address:

- Get a single IPv4 address:

  char *dns_A_Query(char *domain_name, unsigned long wait_option)

- Get multiple IPv4 addresses:

```
unsigned int dns_ALL_Query(unsigned char *domain_name,
                           unsigned char *record_buffer,
                           unsigned int record_buffer_size,
                           unsigned int *record_count,
                           unsigned long wait_option)
```

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1. In the e²studio, import a project for the DNS Query sample application as follows:
   - *~/SDK/apps/common/examples/Network/DNS_Query/projects/da16200*
2. Build the DA16200 SDK, download the RTOS image to the DA16200 EVB, and reboot.
3. Use the console to set up the Wi-Fi station interface.
4. After a connection is made to an AP, the example application starts a DNS query operation with a test URL.

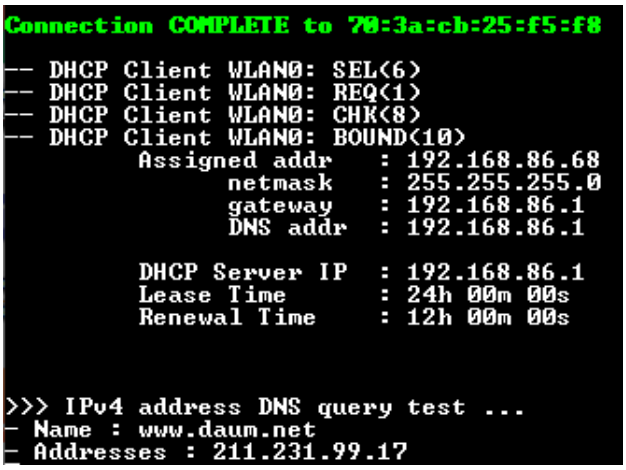

Figure 83: DNS Query Result

12.2.2 DNS Query Initialization

This example creates entry function which is dns_query_sample().

```
void dns_query_sample(void * param)
{
    char       *test_url = NULL;
    if (netmode[WLAN0_IFACE] == DHCPCLIENT) {
      // wait until dhcp is done
      while (da16x_network_main_check_dhcp_state(WLAN0_IFACE) != DHCP_STATE_BOUND) {
          vTaskDelay(100);
      }
    }

    vTaskDelay(500);

    /* Check test url */
    test_url = read_nvram_string("TEST_DOMAIN_URL");
    if (test_url == NULL) {
        test_url = TEST_URL;
    }

    PRINTF("\n\n");
    dns_A_query_sample(test_url);
    vTaskDelete(NULL);
}
```

12.2.3 Get Single IPv4 Address

This example shows the use of the API function “char *dns_A_Query(char *domain_name, unsigned long wait_option)” to get the IPv4 address string with a domain name URL.

```
void dns_A_query_sample(char *test_url_str)
{
```

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```
        char     *ipaddr_str = NULL;

        PRINTF(">>> IPv4 address DNS query test ...\n");

        /* DNS query with test url string */
        ipaddr_str = dns_A_Query(test_url_str, MAX_DNS_QUERY_TIMEOUT);

        /* Fail checking ... */
        if (ipaddr_str == NULL) {
            PRINTF("\nFailed to dns-query with %s\n", test_url_str);
        } else {
            PRINTF("- Name : %s\n", test_url_str);
            PRINTF("- Addresses : %s\n", ipaddr_str);
        }
}
```

12.3 SNTP and Get Current Time

Wi-Fi devices may need to synchronize the device clock on the internet with the use of TLS or communication with the server. DA16200 provides SNTP for this operation and users can use this function to get the current time.

12.3.1 How to Run

1. In the e²studio, import a project for the SNTP and current time sample application as follows:
   - *~/SDK/apps/common/examples/ETC/Cur_Time/projects/da16200*
2. Build the DA16200 SDK, download the RTOS image to the DA16200 EVB, and reboot.
3. Use the console to set up the Wi-Fi station interface.
4. After a connection is made to an AP, the example application starts an SNTP client with test values.

   ~/SDK/apps/common/examples/ETC/Cur_Time/src/cur_time_sample.c

   ```
   #define     TEST_SNTP_SERVER          "time.windows.com"
   #define     TEST_SNTP_RENEW_PERIOD    600
   #define     TEST_TIME_ZONE            (9 * 3600)     // seconds
   #define     SNTP_ENABLE               1
   #define     ONE_SECONDS               100
   #define     CUR_TIME_LOOP_DELAY       10             // seconds
   ```

   Note that the legacy AP must be connected to the internet.
5. After a connection is made to the SNTP server, DA16200 shows the connection result on the debug console.

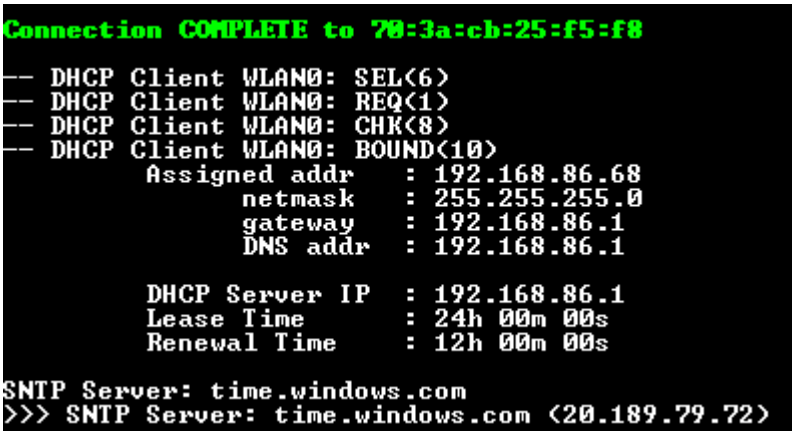

Figure 84: Result of DA16200 SNTP #1

DA16200 periodically gets the current time (the test period: 10 seconds)

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```
>>> SNTP Time sync : 2021.10.07 - 13:37:29
- Current Time : 2021.10.07 13:37:38 (GMT +9:00)
- Current Time : 2021.10.07 13:37:48 (GMT +9:00)
- Current Time : 2021.10.07 13:37:58 (GMT +9:00)
```

Figure 85: Result of DA16200 SNTP #2

12.3.2 Sample Code

1. Configure SNTP client information.
   ~/SDK/apps/common/examples/ETC/Cur_Time/src/cur_time_sample.c

```
void cur_time_sample(void * param)
{
    unsigned char   status;
    __time64_t      now;
    struct   tm *ts;
    char     time_buf[80];

    /* Config SNTP client */
    status = set_n_start_SNTP();
    if (status == pdFAIL) {
            PRINTF("[%s] Faile to start SNTP client ...\n", __func__);
            vTaskDelete(NULL);
            return;
    }
}
```

2. If the SNTP client has already been started with predefined values, then skip this configuration. Set the SNTP server address, time update period, and time zone and finally enable the function.
   ~/SDK/apps/common/examples/ETC/Cur_Time/src/cur_time_sample.c

```
static UCHAR set_n_start_SNTP(void)
{
    unsigned int     status = TX_SUCCESS;

    /* Check current SNTP running status */
    status = getSNTPuse();
    if (status == TX_TRUE) {
            /* Already SNTP module running ... */
            return TX_SUCCESS;
    }

    /* Config and save SNTP server domain */
    status = (unsigned int)setSNTPsrv(TEST_SNTP_SERVER, 0);

    if (status != TX_SUCCESS) {
            PRINTF("[%s] Failed to write nvram operation (SNTP server
          domain)...\n", __func__);
            status = TX_START_ERROR;
            goto _exit;
    }
```

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```
        /* Config and save SNTP periodic renew time : seconds */
        status = (unsigned int)setSNTPperiod(TEST_SNTP_RENEW_PERIOD);

        if (status != TX_SUCCESS) {
                PRINTF("[%s] Failed to write nvram operation (SNTP renew
            period)...\n", __func__);
                status = TX_START_ERROR;
                goto _exit;
        }

        /* Config and save SNTP time zone */
        status = (unsigned int)setTimezone(TEST_TIME_ZONE);

        if (status != TX_SUCCESS) {
                PRINTF("[%s] Failed to write nvram operation (SNTP renew
            period)...\n", __func__);
                status = TX_START_ERROR;
                goto _exit;
        }

        da16x_SetTzoff(TEST_TIME_ZONE);

        /* Config and save SNTP client mode : enable */
        status = setSNTPuse(SNTP_ENABLE);

        if (status != TX_SUCCESS) {
                PRINTF("[%s] Failed to write nvram operation (SNTP mode)...\n",
            __func__);
                status = TX_START_ERROR;
                goto _exit;
        }

    _exit :
        return status;
    }
```

3. After a connection is made to the SNTP server, DA16200 periodically gets the current time.
   ~/SDK/apps/common/examples/ETC/Cur_Time/src/cur_time_sample.c

```
void cur_time_sample(void * param)
{
    ...
    while (1) {
            /* delay */
            vTaskDelay(CUR_TIME_LOOP_DELAY * ONE_SECONDS);

            /* get current time */
            da16x_time64(NULL, &now);
            ts = (struct tm *)da16x_localtime64(&now);
```

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```
            /* make time string */
            da16x_strftime(time_buf, sizeof(time_buf), "%Y.%m.%d %H:%M:%S", ts);

            /* display current time string */
            PRINTF("-  Current  Time : %s (GMT %+02ld:%02ld)\n",
                    time_buf,
                    da16x_Tzoff() / 3600,
                    da16x_Tzoff() % 3600);
        }
    }
```

12.4 SNTP and Get Current Time in DPM

This example application applies to the DPM function. Most parts of the example came from 12.3 and the only different part is to apply the example to the DPM mode.

12.4.1 How to Run

1. In the e²studio, import a project for the SNTP and the current time in the DPM sample application as follows:
   - *~/SDK/apps/common/examples/ETC/Cur_Time_DPM/projects/da16200*
2. Build the DA16200 SDK, download the RTOS image to the DA16200 EVB, and reboot.
3. Use the console to set up the Wi-Fi station interface.
4. After a connection is made to an AP, the example application starts an SNTP client with test values.

~/SDK/apps/common/examples/ETC/Cur_Time_DPM/src/cur_time_dpm_sample.c

```
#define     TEST_SNTP_SERVER            "time.windows.com"
#define     TEST_SNTP_RENEW_PERIOD      600
#define     TEST_TIME_ZONE              (9 * 3600)     // seconds
#define     SNTP_ENABLE                 1
#define     ONE_SECONDS                 100
#define     CUR_TIME_LOOP_DELAY         10             // seconds
```

NOTE
● If the SNTP client is started with pre-defined values, this configuration is ignored. ● The legacy AP must be connected to the internet

5. After a connection is made to the SNTP server, DA16200 shows the connection result on the debug console and goes to DPM sleep mode.

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```
Connection COMPLETE to 70:3a:cb:25:f5:f8

-- DHCP Client WLAN0: SEL(6)
-- DHCP Client WLAN0: REQ(1)
-- DHCP Client WLAN0: CHK(8)
-- DHCP Client WLAN0: BOUND(10)
        Assigned addr    : 192.168.86.68
                 netmask    : 255.255.255.0
                 gateway    : 192.168.86.1
                 DNS addr   : 192.168.86.1

        DHCP Server IP   : 192.168.86.1
        Lease Time       : 24h 00m 00s
        Renewal Time     : 20h 00m 00s

>>> SNTP Server: time.windows.com (20.189.79.72)

>>> SNTP Time sync : 2021.10.07 - 13:48:05
>>> Start DPM Power-Down !!!
```

Figure 86: Result of DA16200 SNTP DPM #1

DA16200 periodically gets the current time (the test period is 10 seconds).

```
rtc_timeout (tid:5)

Wakeup source is 0x82

>>> TIM STATUS: 0x00000010
>>> TIM : FAST
- Current Time : 2021.10.07 13:51:55 (GMT +9:00)
>>> Start DPM Power-Down !!!
PS TIME 109826 us

rtc_timeout (tid:5)

Wakeup source is 0x82

>>> TIM STATUS: 0x00000010
>>> TIM : FAST
- Current Time : 2021.10.07 13:52:05 (GMT +9:00)
>>> Start DPM Power-Down !!!
PS TIME 109892 us
```

Figure 87: Result of DA16200 SNTP DPM #2

12.4.2 Sample Code

The SNTP configuration interface is the same as the non-DPM SNTP example. When the DA16200 wakes up from DPM Sleep mode, use the RTM API to get the current SNTP status, or save the SNTP status into the RTM.

```
~/SDK/apps/common/examples/ETC/Cur_Time_DPM/src/cur_time_dpm_sample.c
static unsigned char set_n_start_SNTP(void)
{
      unsigned char  status = pdPASS;

      /* Check current SNTP running status */
      if (dpm_mode_is_wakeup() == DPM_WAKEUP) {
          status = get_sntp_use_from_rtm();
      } else {
          status = get_sntp_use();
      }

      if (status == pdPASS) {
          long       time_zone;

          /* Already SNTP module running, set again time-zone ... */
          time_zone = get_timezone_from_rtm();
```

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```
            da16x_SetTzoff(time_zone);

            return pdPASS;
        }

        if (dpm_mode_is_wakeup() == NORMAL_BOOT) {
            /* Config and save SNTP server URI */
            status = set_sntp_server(TEST_SNTP_SERVER, 0);

            if (status != pdPASS) {
                PRINTF("Failed to write nvram operation (SNTP server domain)...\n");

                status = pdFAIL;
                goto _exit;
            }

            /* Config and save SNTP periodic renew time : seconds */
            status = set_sntp_period(TEST_SNTP_RENEW_PERIOD);
            if (status != pdPASS) {
                PRINTF("Failed to write nvram operation (SNTP renew period)...\n");
                status = pdFAIL;
                goto _exit;
            }

            /* Config and save SNTP time zone */
            set_time_zone(TEST_TIME_ZONE);
            set_timezone_to_rtm(TEST_TIME_ZONE);
            da16x_SetTzoff(TEST_TIME_ZONE);
            set_time_zone(TEST_TIME_ZONE);

            /* Config, save, and run SNTP client */
            if (set_sntp_use(SNTP_ENABLE) != 0) {
                PRINTF("[%s] Failed to run SNTP...\n", __func__);
                status = pdFAIL;
                goto _exit;
            }

            /* Save config and start SNTP client */
            set_sntp_use_to_rtm(status);
        }

    _exit :
        return status;
    }
```

When connected to the SNTP server, DA16200 starts an RTC timer to periodically get the current time.

```
~/SDK/apps/common/examples/ETC/Cur_Time_DPM/src/cur_time_dpm_sample.c
void cur_time_dpm_sample(void * param)
{
        ...
        /* Register periodic RTC Timer : Get current time */
        if (dpm_mode_is_wakeup() == NORMAL_BOOT){
            /* Time delay for stable running SNTP client */
            vTaskDelay(10);

            status = dpm_timer_create(SAMPLE_CUR_TIME_DPM,
                                      "timer1",
                                      display_cur_time,
                                      CUR_TIME_LOOP_DELAY,
```

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```
                                CUR_TIME_LOOP_DELAY);

            switch ((int)status) {
            case DPM_MODE_NOT_ENABLED    :
            case DPM_TIMER_SEC_OVERFLOW :
            case DPM_TIMER_ALREADY_EXIST:
            case DPM_TIMER_NAME_ERROR    :
            case DPM_UNSUPPORTED_RTM     :
            case DPM_TIMER_REGISTER_FAIL:
            case DPM_TIMER_MAX_ERR       :
               PRINTF(">>> Fail to create %s timer (err=%d)\n",
                     SAMPLE_CUR_TIME_DPM, (int)status);

               // Delay to display above message on console ...
               vTaskDelay(2);

               break;
            }

            /* Set flag to go to DPM sleep 3 */
           dpm_app_sleep_ready_set(SAMPLE_CUR_TIME_DPM);
       } else {
            /* Notice initialize done to DPM module */
            dpm_app_wakeup_done(SAMPLE_CUR_TIME_DPM);
       }

       vTaskDelete(NULL);
  }
```

The SNTP configuration interface is the same as for the non-DPM SNTP example.

```
~/SDK/apps/common/examples/ETC/Cur_Time_DPM/src/cur_time_dpm_sample.c
static void display_cur_time(char *timer_name)
{
       dpm_app_wakeup_done(SAMPLE_CUR_TIME_DPM);

       __time64_t     now;
       struct  tm *ts;
       char    time_buf[80];

       /* get current time */
       da16x_time64(NULL, &now);
       ts = (struct tm *)da16x_localtime64(&now);

       /* make time string */
       da16x_strftime(time_buf, sizeof(time_buf), "%Y.%m.%d %H:%M:%S", ts);

       /* display current time string */
       PRINTF("- Current Time : %s (GMT %+02ld:%02ld)\n",
           time_buf,
           da16x_Tzoff() / 3600,
           da16x_Tzoff() % 3600);

       vTaskDelay(1);

       /* Set flag to go to DPM sleep 3 */
       dpm_app_sleep_ready_set(SAMPLE_CUR_TIME_DPM);
}
```

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12.5 HTTP Client

The DA16200 SDK has a ported lwIP 2.1.2 stack. With this product, an application programmer can develop an HTTP client application that uses lwIP HTTP APIs.

12.5.1 How to Run

1. In the e²studio, import a project for the HTTP_Client sample application as follows:
   - *~/SDK/apps/common/examples/Network/Http_Client/projects/da16200*
2. Build the DA16200 SDK, download the RTOS image to the DA16200 EVB, and reboot.
3. Use the console to set up the Wi-Fi station interface and connect to the AP that is connected to the Internet.
4. Complete the setup and (re)start the sample.

12.5.2 Sample Code

The sample code shows the -get and -post methods. When the sample starts by default, it is executed as a -get method request. To request -post, define ENABLE_METHOD_POST_TEST at the top of the sample code.

To connect to HTTPS(TLS) server, enter "https://" instead of "http://" in the URL address. To set valid time information in the certificate before the HTTPS request, the system's current time must be set (SNTP service must be enabled). Note that the URL and data of the sample code are examples and it needs to modify them according to the user environment.

The sample code is executed as follows:

1. Using the *http_client_parse_uri()* API, set the port number for HTTP or HTTPS and parse the *path* and *host_name*.

```
unsigned char g_http_url[256] = {"http://httpbin.org/get"};
error = http_client_parse_uri(g_http_url, strlen((char *)g_http_url), &request);
if (error != ERR_OK) {
    PRINTF("Failed to set URI(error=%d) \r\n", error);
    goto finish;
}
```

2. Set a variable in the httpc_connection_t type and set the value to be passed to the API.
3. If the user registers the callback function in *headers_done_fn* and *result_fn*, the header response received from the server and the result value of the HTTP Client can be returned.

```
static httpc_connection_t g_conn_settings;
g_conn_settings.use_proxy = 0;
g_conn_settings.altcp_allocator = NULL;
g_conn_settings.headers_done_fn = httpc_cb_headers_done_fn;
g_conn_settings.result_fn = httpc_cb_result_fn;
```

4. When *ENABLE_METHOD_POST_TEST* is defined, users can insert the data they want to send to the server using the *httpc_insert_send_data()* API.

```
#if defined (ENABLE_METHOD_POST_TEST)
error = httpc_insert_send_data("POST", user_post_data, strlen(user_post_data));
if (error != ERR_OK) {
    PRINTF("Failed to insert data\n");
}
#endif
```

5. To perform TLS communication with the HTTP server that requires the HTTP client's certificate, define ENABLE_HTTPS_SERVER_VERIFY_REQUIRED. The certificate must have been previously stored in the TLS area of the DA16200 sflash.

```
if (g_conn_settings.insecure) {
    memset(&g_conn_settings.tls_settings, 0x00,sizeof(httpc_secure_connection_t));
    g_conn_settings.tls_settings.incoming_len = HTTPC_MAX_INCOMING_LEN;
```

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```
    g_conn_settings.tls_settings.outgoing_len = HTTPC_DEF_OUTGOING_LEN;

#ifdef ENABLE_HTTPS_SERVER_VERIFY_REQUIRED
    http_client_read_certs(&g_conn_settings.tls_settings);
    g_conn_settings.tls_settings.auth_mode = MBEDTLS_SSL_VERIFY_NONE;

/* SNI */
    sni_str = read_nvram_string(HTTPC_NVRAM_CONFIG_TLS_SNI);
    …
/* ALPN */
    if (read_nvram_int(HTTPC_NVRAM_CONFIG_TLS_ALPN_NUM, &alpn_cnt) == 0) {
    …

#endif //ENABLE_HTTPS_SERVER_VERIFY_REQUIRED
}
```

6. Call API for get request. User calls httpc_get_file() or httpc_get_file_dns() depending on whether hostname needs a DNS query. If the request is successful, the user can receive payload data through the registered httpc_cb_recv_fn callback function.

```
if (isvalidip((char *)request.hostname)) {
    ip4addr_aton(g_request.hostname, &g_server_addr);
    error = httpc_get_file(&g_server_addr,
                           g_request.port,
                           (char *)&g_request.path[0],
                           &g_conn_settings,
                           (altcp_recv_fn)httpc_cb_recv_fn,
                           NULL,
                           &g_connection);
} else {
    error = httpc_get_file_dns((char *)&g_request.hostname[0],
                               g_request.port,
                               (char *)&g_request.path[0],
                               &g_conn_settings,
                               (altcp_recv_fn)httpc_cb_recv_fn,
                               NULL,
                               &g_connection);
}
```

7. The httpc_cb_recv_fn() callback function receives a pbuf pointer. p->payload is the data received from the server.

```
static err_t httpc_cb_recv_fn(void *arg, struct tcp_pcb *tpcb,
                              struct pbuf *p, err_t err)
{
    if (p == NULL) {
       PRINTF("\n[%s:%d] Receive data is NULL !! \r\n", __func__, __LINE__);
       return ERR_BUF;
    } else {
       PRINTF("\n[%s:%d] Received length = %d \r\n", __func__, __LINE__, p->len);
       hexa_dump_print("Received data \r\n", p->payload,
                       p->len, 0, OUTPUT_HEXA_ASCII);
    }

    return ERR_OK;
}
```

12.6 HTTP Client in DPM

The DA16200 SDK has a ported lwIP 2.1.2 stack. With this product, an application programmer can develop an HTTP client application that uses lwIP HTTP APIs.

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12.6.1 How to Run

1. In the e²studio, import a project for the HTTP_Client sample application as follows:
   - *~/SDK/apps/common/examples/Network/Http_Client_DPM/projects/ da16200*
2. Build the DA16200 SDK, download the RTOS image to the DA16200 EVB, and reboot.
3. Use the console to set up the Wi-Fi station interface and connect to the AP that is connected to the Internet.
4. Complete the setup and (re)start the sample.

12.6.2 Sample Code

The sample code shows the -get and -post methods. When the sample starts by default, it is executed as a -get method request. To request -post, define ENABLE_METHOD_POST_TEST at the top of the sample code.

To connect to HTTPS(TLS) server, enter "https://" instead of "http://" in the URL address. To set valid time information in the certificate before the HTTPS request, the system's current time must be set (SNTP service must be enabled). Note that the URL and data of the sample code are examples and it needs to modify them according to the user environment.

The sample code is executed as follows:

1. If an application that uses the HTTP protocol is registered in DPM, a setting must be made not to enter DPM_SLEEP while HTTP transmission (request/response) is in progress. Set DPM_SLEEP after all transfers are complete.

```
void http_client_dpm_sample_entry(void * param)
{
    ...
    dpm_app_register(HTTP_CLIENT_SAMPLE_TASK_NAME, request.port);
    dpm_app_sleep_ready_clear(HTTP_CLIENT_SAMPLE_TASK_NAME);
    ...
}

static void httpc_cb_result_fn(void *arg, httpc_result_t httpc_result, u32_t
                            rx_content_len, u32_t srv_res, err_t err)
{
    PRINTF("\n httpc_result: %d, received: %d byte\r\n",
            httpc_result, rx_content_len);
    dpm_app_sleep_ready_set(HTTP_CLIENT_SAMPLE_TASK_NAME);
    return;
}
```

2. Using the *http_client_parse_uri()* API, set the port number for HTTP or HTTPS and parse the *path* and *host_name*.

```
unsigned char g_http_url[256] = {"http://httpbin.org/get"};

error = http_client_parse_uri(g_http_url, strlen((char *)g_http_url), &request);
if (error != ERR_OK) {
    PRINTF("Failed to set URI(error=%d) \r\n", error);
    goto finish;
}
```

3. Set a variable in the httpc_connection_t type and set the value to be passed to the API.
4. If the user registers the callback function in *headers_done_fn* and *result_fn*, the header response received from the server and the result value of the HTTP Client can be returned.

```
static httpc_connection_t conn_settings;
g_conn_settings.use_proxy = 0;
g_conn_settings.altcp_allocator = NULL;
g_conn_settings.headers_done_fn = httpc_cb_headers_done_fn;
g_conn_settings.result_fn = httpc_cb_result_fn;
```

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5. When *ENABLE_METHOD_POST_TEST* is defined, users can insert the data they want to send to the server using the *httpc_insert_send_data()* API.

```
#if defined (ENABLE_METHOD_POST_TEST)
  error = httpc_insert_send_data("POST", user_post_data, strlen(user_post_data));
  if (error != ERR_OK) {
    PRINTF("Failed to insert data\n");
  }
#endif
```

6. To perform TLS communication with the HTTP Server that requires the HTTP Client's certificate, define *ENABLE_HTTPS_SERVER_VERIFY_REQUIRED*. The certificate must have been previously stored in the TLS area of the DA16200 sflash.

```
if (g_conn_settings.insecure) {
    memset(&g_conn_settings.tls_settings, 0x00,sizeof(httpc_secure_connection_t));
    g_conn_settings.tls_settings.incoming_len = HTTPC_MAX_INCOMING_LEN;
    g_conn_settings.tls_settings.outgoing_len = HTTPC_DEF_OUTGOING_LEN;
#ifdef ENABLE_HTTPS_SERVER_VERIFY_REQUIRED
    http_client_read_certs(&g_conn_settings.tls_settings);
    g_conn_settings.tls_settings.auth_mode = MBEDTLS_SSL_VERIFY_NONE;

/* SNI */
    sni_str = read_nvram_string(HTTPC_NVRAM_CONFIG_TLS_SNI);
    …
/* ALPN */
    if (read_nvram_int(HTTPC_NVRAM_CONFIG_TLS_ALPN_NUM, &alpn_cnt) == 0) {
    …

#endif //ENABLE_HTTPS_SERVER_VERIFY_REQUIRED
}
```

7. Call API for get request. User calls *httpc_get_file()* or *httpc_get_file_dns()* depending on whether hostname needs a DNS query. If the request is successful, the user can receive payload data through the registered *httpc_cb_recv_fn* callback function.

```
if (isvalidip((char *)g_request.hostname)) {
    ip4addr_aton(g_request.hostname, & g_server_addr);
    error = httpc_get_file(&g_server_addr,
                           g_request.port,
                           char *)&g_request.path[0],
                           & g_conn_settings,
                           (altcp_recv_fn)httpc_cb_recv_fn,
                           NULL,
                           &connection);
} else {
    error = httpc_get_file_dns((char *)&g_request.hostname[0],
                               g_request.port,
                               (char *)&g_request.path[0],
                               &g_conn_settings,
                               altcp_recv_fn)httpc_cb_recv_fn,
                               NULL,
                               &connection);
}
```

8. The httpc_cb_recv_fn() callback function receives a pbuf pointer. p->payload is the data received from the server.

```
static err_t httpc_cb_recv_fn(void *arg, struct tcp_pcb *tpcb,
                              struct pbuf *p, err_t err)
{
    if (p == NULL) {
      PRINTF("\n[%s:%d] Receive data is NULL !! \r\n", __func__, __LINE__);
      return ERR_BUF;
    } else {
```

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```
        PRINTF("\n[%s:%d] Received length = %d \r\n", __func__, __LINE__, p->len);
        hexa_dump_print("Received data \r\n", p->payload,
                        p->len, 0, OUTPUT_HEXA_ASCII);
    }

    return ERR_OK;
}
```

12.7 HTTP Server

The DA16200 SDK has a ported lwIP 2.1.2 stack. With this product, an application programmer can develop an HTTP server application that uses lwIP HTTP APIs.

12.7.1 How to Run

1. In the e²studio, import a project for the HTTP_Server sample application as follows:
   - *~/SDK/apps/common/examples/Network/Http_Server/projects/da16200*
2. Build the DA16200 SDK, download the RTOS image to the DA16200 EVB, and reboot.
3. Use the console to set up the Wi-Fi station interface and connect to the AP.
4. Complete the setup and (re)start the sample.

12.7.2 Sample Code

The sample code shows the -get methods.

1. The HTTP Server sample code supports both HTTP and HTTPS (Default is HTTP).
   To operate with HTTPS, define ENABLE_HTTPS_SERVER as shown below. Also, update the certificate embedded in the code (tls_srv_sample_cert, tls_srv_sample_key) as needed.
   ```
   /// HTTPS server
   #define ENABLE_HTTPS_SERVER
   ```
2. The HTTP server can be operated simply by calling the httpd_init() API.

   Also, user callback function can be registered as argument value. The registered callback function is called when data is received from the HTTP Client.

```
/* Callback function*/
static err_t http_server_cb_recv_fn(struct pbuf *p, err_t err)
{
    err_t error = ERR_OK;
    extern void hex_dump(UCHAR * data, UINT length);

    PRINTF("[%s] err = %d, p->tot_len = %d, p->len = %d\n", __func__, err, p-
>tot_len, p->len);
    hex_dump(p->payload, p->len);

    return error;
}

/* Server task */
static void http_server_sample(void *params)
{
    httpd_init((altcp_user_recv_fn)http_server_cb_recv_fn);

    PRINTF("[%s] HTTP-Server Start!! \r\n", __func__);

    while (1){
        vTaskDelay(100);
    }
    return ;
}
```


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3. The HTTPS server must set the key and certificate information required for TLS.

```
struct altcp_tls_config *tls_srv_sample_config = NULL;
...
tls_srv_sample_config =
altcp_tls_create_config_server_privkey_cert(tls_srv_sample_key,
                                            tls_srv_sample_key_len,
                                            NULL,
                                            0,
                                            tls_srv_sample_cert,
                                            tls_srv_sample_cert_len);
if (!tls_srv_sample_config) {
    PRINTF("[%s] Failed to create tls config\r\n", __func__);
    goto end_of_task;
}

httpd_inits(tls_srv_sample_config, (altcp_user_recv_fn)http_server_cb_recv_fn);

PRINTF("[%s] HTTPS-Server Start!! \r\n", __func__);

end_of_task:
  while (1) {
      vTaskDelay(100);
  }
```

4. If the HTTP Server works successfully, test the **-get** method as follows.
   Use the web browser of the test PC that is connected to the same network.
   - Access from a Web browser

   http://[Server IP]/index.html
   - The page displayed is located below

   [~/sdk/libraries/3rdloty/lwip/src/src/apps/http/fs/index.html]

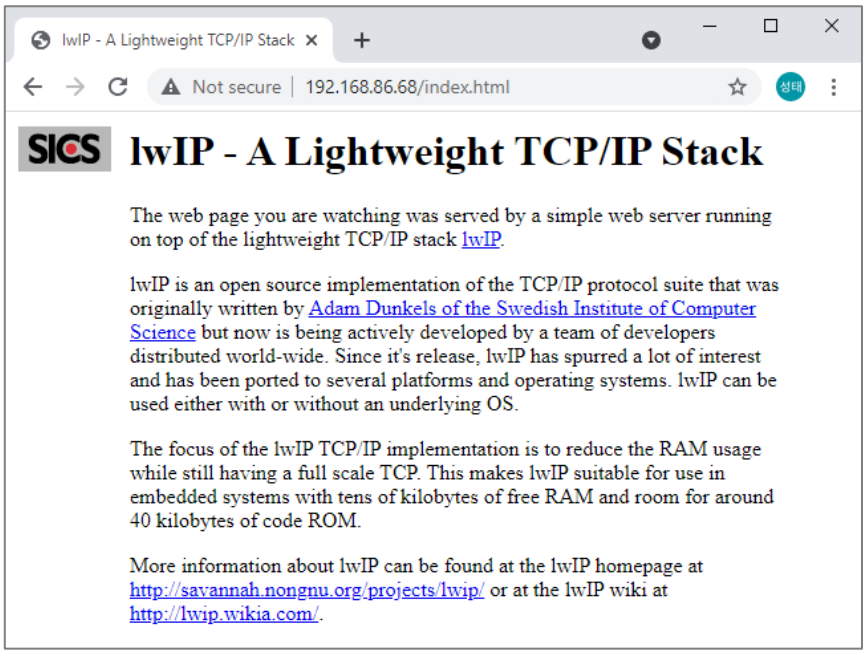

Figure 88: Result of DA16200 HTTP Server

   - For POST, write "/post" at the end of the URL.

   http://[Server IP]/post

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NOTE

To modify the html page, see the readme.txt file in
.\core\libraries\3rdparty\lwip\src\apps\http\makefsdata
And follow the steps below to create new fsdata.c code suitable for httpd for given html pages.

1. Make sure to install Perl or else install the Perl.
2. Run the Git bash or Unix based terminal, or windows command prompt if Cygwin is installed.
3. Navigate to the directory in SDK: .\core\libraries\3rdparty\lwip\src\apps\http\makefsdata
4. Copy makefsdata and rename it (to makefsdata_run for example) and rename the current fs_data.c as well like fs_data.c.ori for future reference/compare when needed.
5. Type this command "perl makefsdata_run", it will overwrite the fsdata.c.
6. After the fsdata.c is created, go to the end of the file and add this code manually in all const struct fsdata_file file_*** variables.
   ",FS_FILE_FLAGS_HEADER_INCLUDED | FS_FILE_FLAGS_HEADER_PERSISTENT,"
7. The code before the update is as follows:
   const struct fsdata_file file_404_html[] = {{NULL, data_404_html, data_404_html + 10, sizeof(data_404_html) - 10}};
   const struct fsdata_file file_img_sics_gif[] = {{file_404_html, data_img_sics_gif, data_img_sics_gif + 14, sizeof(data_img_sics_gif) - 14}};
   const struct fsdata_file file_index_html[] = {{file_img_sics_gif, data_index_html, data_index_html + 12, sizeof(data_index_html) - 12}};
8. It must be:
   const struct fsdata_file file_404_html[] = {{NULL, data_404_html, data_404_html + 10, sizeof(data_404_html) - 10, FS_FILE_FLAGS_HEADER_INCLUDED | FS_FILE_FLAGS_HEADER_PERSISTENT,}};
   const struct fsdata_file file_img_sics_gif[] = {{file_404_html, data_img_sics_gif, data_img_sics_gif + 14, sizeof(data_img_sics_gif) - 14, FS_FILE_FLAGS_HEADER_INCLUDED | FS_FILE_FLAGS_HEADER_PERSISTENT,}};
   const struct fsdata_file file_index_html[] = {{file_img_sics_gif, data_index_html, data_index_html + 12, sizeof(data_index_html) - 12, FS_FILE_FLAGS_HEADER_INCLUDED | FS_FILE_FLAGS_HEADER_PERSISTENT,}};
9. Build the SDK and try again.

12.8 WebSocket Client

This section describes the behavior of the example WebSocket Client application and how to build it.

NOTE

WebSocket client does not support DPM mode.

12.8.1 How to Run

1. In the e²studio, import a project for the Websocket_Client application as follows:
   - *~/SDK/apps/common/examples/Network/WebSocket_Client/projects/da16200*
2. To set the WebSocket Server URI in the WebSocket Client Sample, edit the source code:
   ~/SDK/apps/common/examples/Network/WebSocket_Client/src/websocket_client_sample.c
   #define WEBSOCKET_SERVER_URI *"ws(wss)://xxxx.xxxx.xxxx"*
3. Build the DA16200 SDK, download the RTOS image to the DA16200 EVB, and reboot.
4. Use the console to set up the Wi-Fi station interface and connect to the AP that is connected to the Internet.
5. Complete the setup and (re)start the sample.

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12.8.2 Sample Code

When the WebSocket client application starts, it tries to connect to a WebSocket Server and send a message 10 times. The URI and data of the example code are for demonstration purposes and can be modified as required to create a custom application. To use the WebSocket Secure connection, enter "wss://" instead of "ws://" in the URI.

The sample code is executed as follows:

1. Set *websocket_cfg.uri* for the WebSocket Server URI and WebSocket initializes with the WebSocket configurations.

```
websocket_cfg.uri = WEBSOCKET_SERVER_URI;
WS_LOGI(TAG, "Connecting to %s...\n", websocket_cfg.uri);
websocket_client_handle_t client = websocket_client_init(&websocket_cfg);
```

2. To receive event data, register *websocket_client_event_callback* function before starting the WebSocket Client.

   static void ws_event_handler (websocket_client_event_id_t event_id, websocket_client_event_data_t *event_data)

```
{
  websocket_client_event_data_t *data = (websocket_client_event_data_t
*)event_data;

    switch (event_id) {
    case WEBSOCKET_CLIENT_EVENT_CONNECTED:
        WS_LOGW(TAG, "WEBSOCKET_CONNECTED\n");
        break;
    case WEBSOCKET_CLIENT_EVENT_DISCONNECTED:
        WS_LOGW(TAG, "WEBSOCKET_DISCONNECTED\n");
        break;
    case WEBSOCKET_CLIENT_EVENT_DATA:
          …
          …
        if(data->op_code == WS_TRANSPORT_OPCODES_CLOSE) {
          WS_LOGW(TAG, "Websocket Server Closed\n");
          websocket_client_abort_connection(data->client);
        }
        xTimerReset(shutdown_signal_timer, portMAX_DELAY);
        break;
    case WEBSOCKET_CLIENT_EVENT_ERROR:
        WS_LOGE(TAG, "WEBSOCKET_ERROR\n");
        break;
    }
}

websocket_client_start(client, ws_event_handler);
```

3. When the WebSocket Client connects to the server, it sends a message 10 times using *websocket_client_send_text()* API.

   If no event data is received for 5 seconds, *shutdown_signal_timer* disconnects the WebSocket connection.

```
while (i < 10) {
    if (websocket_client_is_connected(client)) {
        int len = sprintf(data, "hello %04d", i++);
        WS_LOGI(TAG, "Sending %s\n", data);
        websocket_client_send_text(client, data, len, portMAX_DELAY);
    }
```

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```
        vTaskDelay(1000 / portTICK_PERIOD_MS);
    }
```

4. *shutdown_signal_timer* discdonnects the WebSocket connection using the *`websocket_client_stop()`*API.

```
if(websocket_client_stop(client)== WS_OK){
   WS_LOGI(TAG, "Websocket Stopped\n");
 }
```

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13 Network Examples: OTA

13.1 Overview

The DA16200/DA16600 provides support for over the air (OTA) firmware update using the HTTP protocol. The chip operates as an HTTP client which can download and update new firmware from an HTTP server.

The DA16200 firmware image set consists of Bootloader (Second bootloader) and RTOS. The boot loader cannot be updated via OTA, but only RTOS. This product allows application programmers to develop an OTA firmware application that uses the OTA APIs. In addition, users can update certificates such as TLS Certificate Key #1 and TLS Certificate Key #2, and support a firmware update of MCU. Users can easily develop these functions using the API provided by the DA16200/DA16600 SDK.

NOTE
When DPM mode is enabled and an OTA (firmware) update is in progress, DPM Sleep Mode will be paused temporarily due to SFLASH write operations. Once the firmware update is complete, DPM Sleep Mode will return to normal operation.

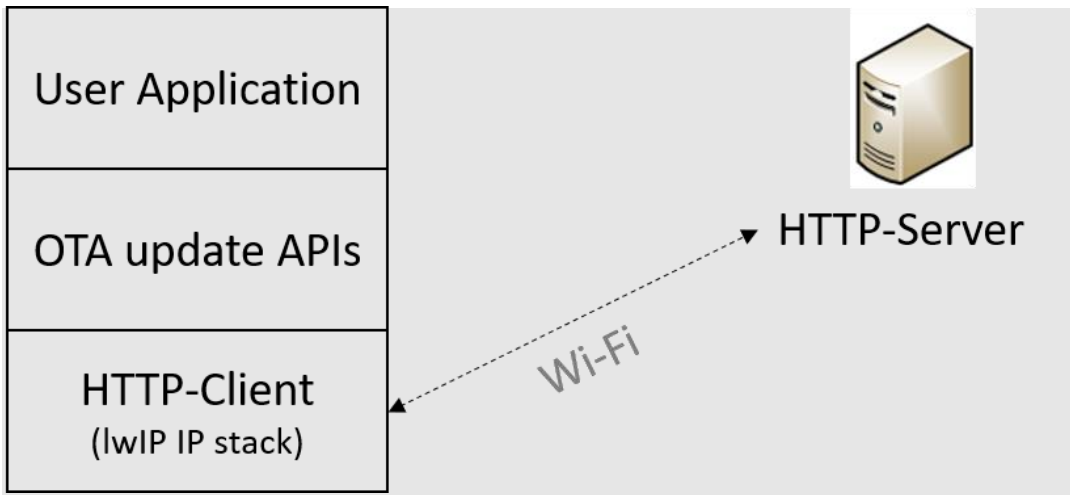

Figure 89: OTA Update Layer

13.2 SFLASH Memory Area

The DA16200/DA16600 does not support file systems, so the firmware should be stored in the SFLASH memory. The SFLASH is divided into several areas as shown in the Table 30. Among them, the areas that users can directly access are as follows:

- User accessible SFLASH areas:
  - RTOS #0
  - RTOS #1
  - TLS Certificate #1
  - TLS Certificate #2
  - User Area

NOTE
Incorrect access to other areas may cause serious failure in the system.

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Table 30: 4 MB SFLASH Memory Map

Address	Name		Size (kB)
0x0000_0000	2nd Bootloader		136
0x0002_2000	Boot Index		4
0x0002_3000	RTOS #0		1788
0x001E_2000	RTOS #1		1788
0x003A_1000	Reserved Area		4
0x003A_2000	Debug / RMA Certificate		4
0x003A_3000	TLS Certificate #1 (MQTT)	CA	4
0x003A_4000		Cert	4
0x003A_5000		Private key	4
0x003A_6000		Diffie-Hellmann key	4
0x003A_7000	TLS Certificate #2 (HTTPs / OTA)	CA	4
0x003A_8000		Cert	4
0x003A_9000		Private key	4
0x003A_A000		Diffie-Hellmann key	4
0x003A_B000	NVRAM #0		4
0x003A_C000	NVRAM #1 (Backup)		4
0x003A_D000	User Area (including DA14531 image, See NOTE)		256
0x003E_D000	TLS Certificate Key #3 (WPA Enterprise)	CA	4
0x003E_E000		Cert	4
0x003E_F000		Private	4
0x003F_0000		Diffie-Hellmann key	4
0x003F_1000	TLS Certificate Key #4 (Reserved)	CA	4
0x003F_2000		Certificate	4
0x003F_3000		Private Key	4
0x003F_4000		Diffie-Hellmann key	4
0x003F_5000	NVRAM FOOTPRINT		4
0x003F_6000	AT-CMD TLS Certificate Key #0 ~ #9		40

NOTE
For DA16600, the DA14531 image is stored in the User Area (0x003A_D000 ~ 0x003C_1FFF). See Ref. [4] for further details.

13.3 HTTP Protocol

The DA16200/DA16600 supports HTTP/HTTPS 1.1 and requests a firmware download to the HTTP server by using the GET method of the HTTP client.

The OTA update application must know the URL of the HTTP server before requesting a download. How to obtain the URL depends on the user's preference. When using HTTPS, the DA16200/DA16600 should have at least 36 kB of heap memory for TLS encryption and decryption. The user can print the current memory usage from the terminal.

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- CLI commands
  [/DA16200] # sys.os.heap
  [/DA16200] # sys.os.pool
- API

```
extern void memoryPoolInfo(void);
extern void   cmd_heapinfo_func(int argc, char *argv[]);
memoryPoolInfo();
cmd_heapinfo_func(0, NULL);
```

13.4 OTA Firmware Update

The OTA firmware update is divided into two stages: **DOWNLOAD** and **RENEW**.

DOWNLOAD refers to the process of downloading the new firmware from the OTA server. In this case, the firmware is not yet applied.

RENEW is the process of applying the downloaded firmware. When the firmware is successfully applied, the new firmware will be executed after reboot.

13.4.1 Header

Figure 90 shows DA16200/DA16600 header information as an example. Header information is 96 bytes and is automatically inserted when the firmware is built. The red box in Figure 90 is the magic number and version information. The yellow box is information for checking firmware Cyclic Redundancy Check (CRC). Users only need to check the version information in the red box.

```
Offset(h) 00 01 02 03 04 05 06 07 08 09 0A 0B 0C 0D 0E 0F
00000000  46 43 39 4B 10 61 46 52 00 00 00 00 00 00 00 00  FC9K.aFR........
00000010  46 52 54 4F 53 2D 47 45 4E 30 31 2D 30 31 2D 31  FRTOS-GEN01-01-1
00000020  33 30 33 32 2D 30 30 30 30 30 30 00 00 00 00 00  3032-000000.....
00000030  00 00 00 00 00 00 00 00 90 9D 0D 00 6F 5B F1 02  ............o[ñ.
00000040  00 03 03 02 5D C0 27 EA E0 89 0D 00 00 14 10 00  ....]À'êà‰......
00000050  48 03 00 00 A2 29 B2 0B 48 03 00 00 65 75 AB 41  H...¢)².H...eu«A
00000060  64 03 00 00 8A 6F 96 4D 00 00 00 00 00 00 00 00  d...Šo–M........
00000070  63 6B 42 53 00 00 01 00 72 00 00 00 01 00 00 00  ckBS....r.......
00000080  C0 31 92 46 80 0A D7 85 66 8E F2 EC 3D 3B 2D B2  À1'F€.×…fŽòì=;-²
00000090  7E BD D7 B2 8A B9 9C 96 DD CB 86 10 6E 71 FC 00  ~½×²Š¹œ–ÝË†.nqü.
000000A0  13 1D 97 FF FC 1F 12 31 A5 05 C1 BA C2 04 E6 0A  ..—ÿü..1¥.Á°Â.æ.
```

Figure 90: Firmware Header Information

13.4.2 Version

DA16200/DA16600's RTOS has unique version rules for system protection. The version name is inserted as a string of up to 39 bytes including the separator "-" in the header part of the firmware image at build time.

There are five elements in the version string, separated by "-": Type, Vendor, Major, Minor, and Customer. For example, FRTOS-GEN01-01-12345-000001.

The file name of the firmware does not have to be the same as the version. DA16200/DA16600 only refers to the version inserted in the firmware header.

Version String

Type-Vendor-Major-Minor-Customer

- Type (6 bytes): Identify the type of firmware.
- Vendor (6 bytes): Vendor classification.

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- Major (3 bytes): Major number to check compatibility.
- Minor (10 bytes): SDK patch number.
- Customer (10 bytes): User configurable version.

Type-Vendor-Major determines whether DOWNLOAD or RENEW is compared to the version of firmware currently in operation. *Minor-Customer* can be used by the user for firmware version management.

Users can change the customer version by editing ..\version\3rd_customer_build_num.h. If users change the customer version and build the SDK, the customer version is applied to the image.

13.4.3 Result Code

All APIs provided by OTA update return the result codes as shown in the Table 31. It is delivered through the callback function connected with DOWNLOAD and RENEW APIs.

Table 31: Result Code

Result Code	Value	Description
OTA_SUCCESS	0x00	Return success.
OTA_FAILED	0x01	Return failed.
OTA_ERROR_SFLASH_ADDR	0x02	SFLASH address is wrong.
OTA_ERROR_TYPE	0x03	FW type is unknown.
OTA_ERROR_URL	0x04	Server URL is unknown.
OTA_ERROR_SIZE	0x05	FW size is too big.
OTA_ERROR_CRC	0x06	CRC is not correct.
OTA_VERSION_UNKNOWN	0x07	FW version is unknown.
OTA_VERSION_INCOMPATI	0x08	FW version is incompatible.
OTA_NOT_FOUND	0x09	FW was not found on the server.
OTA_NOT_CONNECTED	0x0A	Failed to connect to the server.
OTA_NOT_ALL_DOWNLOAD	0x0B	All new FWs have not been downloaded.
OTA_MEM_ALLOC_FAILED	0x0C	Failed to allocate memory.
OTA_BLE_VERSION_UNKNOWN	0xA1	BLE FW version is unknown.

13.4.4 Download

The download step is the process of downloading firmware from the OTA server and saving it into the SFLASH area.

The communication protocol with the OTA server uses HTTP and can be implemented using the HTTP API supported by lwIP. Therefore, the process of communicating with HTTP-server works the same as lwIP's HTTP Client.

The download sequence proceeds as follows, and both success and failure results can be delivered through the callback function (see Table 31 for results):

1. Request a query from the HTTP server.
2. Confirm that the response was successfully received from the HTTP server. If the server connection fails or receives a failure response, the download will be terminated, and the result will be transferred to the callback function. See Table 31 for result values.
3. Check the magic number and version name in the firmware header, and if they do not match, the download is terminated, and the result is transferred to the callback function.
4. If the magic number and version name are normal, the downloaded data is written to SFLASH. The SFLASH address where the data is written is automatically determined by the boot index

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(see Section 13.4.5.1). When the download is completed successfully, the entire firmware stored in SFLASH will have a CRC check.

5. When the CRC check is successfully completed, the result value of 0x00 is transferred to the callback function and the download is terminated.

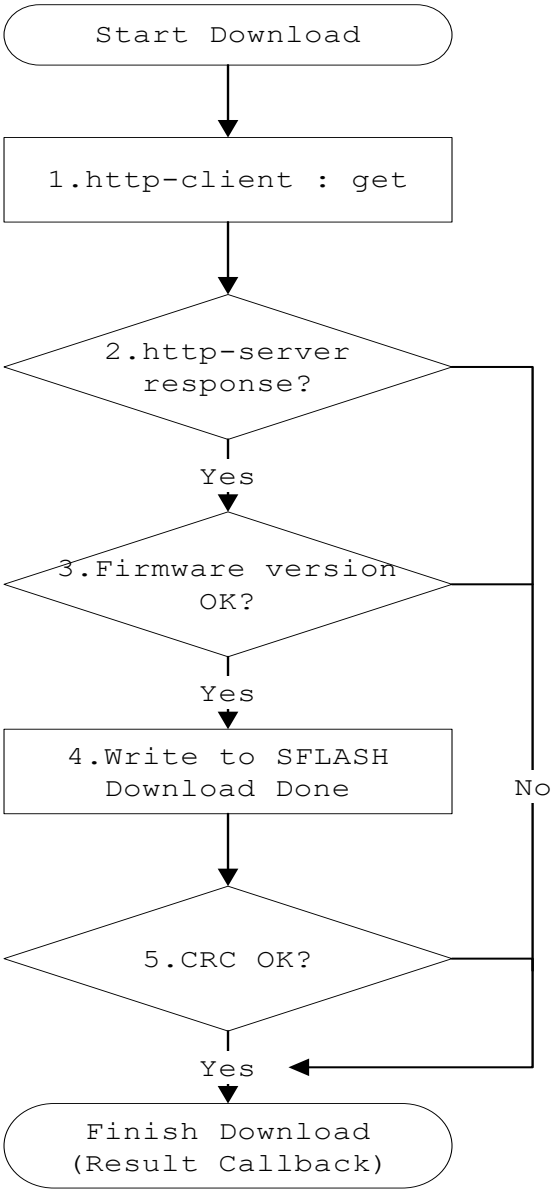

Figure 91: Firmware DOWNLOAD

13.4.5 Renew

RENEW only operates when the firmware download is successful. DA16200/DA16600 should have the download history after power is on.

1. Check whether the download was successful. After turning on the power, check the download history.
2. Check the CRC of the firmware stored in the SFLASH. In case of failure, RENEW ends and the result is transmitted to the callback function.

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3. Check the firmware version stored in the flash. In case of failure, RENEW ends and the result is transmitted to the callback function.
4. Determine if the new firmware is normal and change the boot index to the new firmware location.

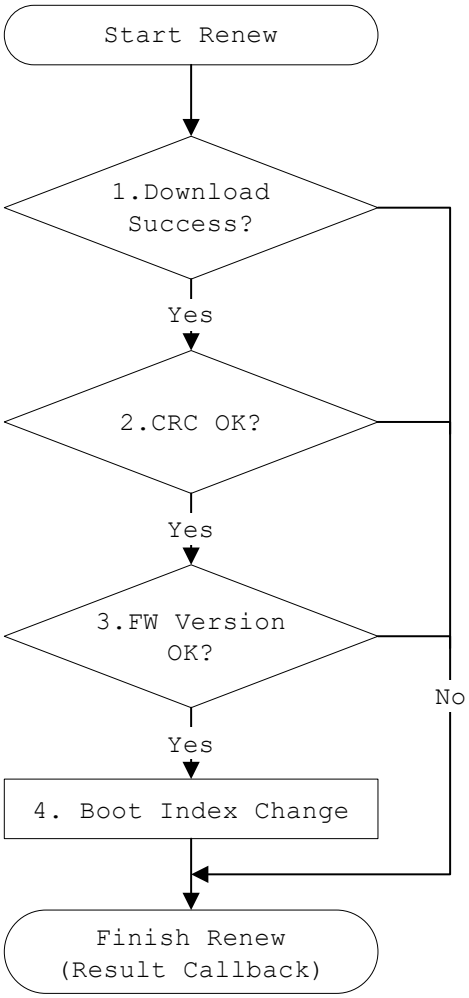

Figure 92: Firmware RENEW

13.4.5.1 Boot Index

DA16200/DA16600 is divided into firmware download area and current area for OTA firmware update. The two areas are toggled on each other by the boot index. For example, if the boot index value is 0, it operates as the firmware stored in the SFLASH RTOS #0 area upon booting, and the newly downloaded firmware is stored in RTOS #1. After that, if RENEW is operated successfully, the boot index value is changed to 1, rebooted, and the firmware stored in the SFLASH RTOS#1 area is operated.

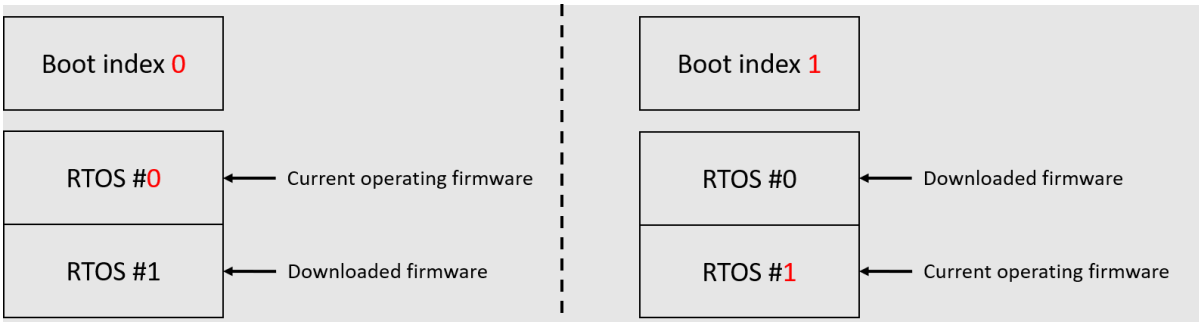

Figure 93: Boot Index Operation

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13.5 Application Programming Interface

It describes the structures and APIs required for the OTA firmware update application.

13.5.1 Type

OTA update task is operated based on the type defined in the OTA update type. The operation sequence is tailored to the specified type.

Table 32: OTA Update Type

Name	ota_update_type
Description	Identify and specify targets for OTA updates.
	/// Operation step of process typedef enum { OTA_TYPE_INIT, // Init value OTA_TYPE_RTOS, // RTOS OTA_TYPE_BLE_FW, // BLE firmware, for DA166x OTA_TYPE_BLE_COMBO, // RTOS and BLE firmware, for DA166x OTA_TYPE_MCU_FW, // MCU firmware, not DA16x OTA_TYPE_CERT_KEY, // Certificate or Key OTA_TYPE_UNKNOWN // Unknown value } ota_update_type;

13.5.2 Structure

OTA UPDATE CONFIG sets the necessary parameters when calling OTA firmware update API.

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Table 33: OTA Update Configuration

Name	OTA_UPDATE_CONFIG
Description	Contains information to be passed as argument values to OTA update APIs.
	/// OTA update configuration structure typedef struct { /// Update type. ota_update_type update_type; /// Server address where firmware is located. char url[OTA_HTTP_URL_LEN]; /// Callback function pointer to check the download status. void (*download_notify)(ota_update_type update_type, UINT ret_status, UINT progress); /// Callback function pointer to check the renew state. Only for RTOS. void (*renew_notify)(UINT ret_status); /// If the value is true, if the new firmware download is successful, it will reboot with the new firmware. Only for RTOS UINT auto_renew; /// Address of sflash where other_fw is stored. Only for MCU_FW and CERT_KEY UINT download_sflash_addr; #if defined (__BLE_COMBO_REF__) /// Server address where ble firmware is located. Char url_ble_fw[OTA_HTTP_URL_LEN]; #endif /* __BLE_COMBO_REF__ */ } OTA_UPDATE_CONFIG;

13.5.3 APIs

It describes the APIs required for the OTA firmware update application.

Table 34: APIs for OTA Firmware

Item		Description
UINT ota_update_start_download(OTA_UPDATE_CONFIG *ota_update_conf)		
Parameter	[in] ota_update_conf	The pointer of OTA_UPDATE_CONFIG structure. update_type: Update type. url: Server address where firmware is located. (*download_notify)(ota_update_type update_type, UINT ret_status, UINT progress): Callback function pointer to check the download status. (*renew_notify)(UINT ret_status): Callback function pointer to check the renew state. Only for RTOS. auto_renew: If the value is true, if the new firmware download is successful, it will reboot with the new firmware. Only for RTOS. download_sflash_addr: This can set the SFLASH address to download MCU_FW, BLE_FW and CERT_KEY excluding RTOS within the User Area range. The default value is 0x003A_D000.

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Item		Description
		url_ble_fw: Server address where ble fw is located when (__BLE_COMBO_REF__) is defined.
Return		Returns 0x00 on success. See Table 31.
Description		HTTP Client task is created and sent a query to the HTTP server. It checks the version compatibility of the firmware received from the server and writes it to the download area of SFLASH.
UINT ota_update_stop_download(void)		
Parameter	None	
Return		Returns 0x00 on success. See Table 31.
Description		A download can be stopped while downloading from the HTTP server.
UINT ota_update_get_download_progress(ota_update_type update_type)		
Parameter	[in] update_type	Specifies the type to be updated.
Return		Returns a value between 0 and 100. If the download was successful, it returns 100.
Description		Checks the progress while downloading or after completion.
UINT ota_update_start_renew(OTA_UPDATE_CONFIG *ota_update_conf)		
Parameter	[in] ota_update_conf	The pointer of OTA_UPDATE_CONFIG structure.
Return		Returns 0x00 on success. See Table 31.
Description		Checks the version compatibility and CRC, changes the boot index to the new firmware location, and then reboots automatically.
UINT ota_update_get_new_sflash_addr(UINT update_type)		
Parameter	[in] update_type	Specifies the type to be updated.
Return		Returns the SFLASH address.
Description		The user can know the address of SFLASH where the new firmware(data) downloaded from the server is stored.
UINT ota_update_read_flash(UINT addr, VOID *buf, UINT len)		
Parameter	[in] addr [out] buf [in] len	SFLASH address (hex). Buffer pointer to store read data. Length to read.
Return		Returns 0x00 on success. See Table 31.
Description		Reads SFLASH as much as the input address and length.
UINT ota_update_erase_flash(UINT addr, UINT len)		
Parameter	[in] addr [in] len	SFLASH address (hex). Length to erase.
Return		Returns erased length.
Description		Erases SFLASH as much as the input address and length.
UINT ota_update_copy_flash(UINT dest_addr, UINT src_addr, UINT len)		
Parameter	[in] dest_addr [in] src_addr	dest_addr Destination SFLASH address (hex). src_addr Source SFLASH address (hex).

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Item		Description
	[in] len	Length to copy.
Return		Returns 0x00 on success. See Table 31.
Description		Copies as much as the length from SFLASH address src_addr to dest_addr.
UINT ota_update_set_mcu_fw_name(char *name)		
Parameter	[in] name	Input the firmware name (version). Maximum 8 bytes.
Return		Returns 0x00 on success. See Table 31.
Description		Sets the name (version) of MCU FW to be downloaded to SFLASH. If not set, it is set as the default string. /* ota_update.h */ #define OTA_MCU_FW_NAME "MCU_FW"
UINT ota_update_get_mcu_fw_name(char *name)		
Parameter	[out] name	Pointer to get the name (version) of MCU FW.
Return		Returns 0x00 on success. See Table 31.
Description		Gets name (version) of MCU FW downloaded to SFLASH.
UINT ota_update_get_mcu_fw_info(char *name, UINT *size, UINT *crc)		
Parameter	[out] name [out] size [out] crc	Pointer to get the name (version) of MCU FW. Pointer to get the size of MCU FW. Pointer to get the CRC32 value of MCU FW.
Return		Returns 0x00 on success. See Table 31.
Description		Gets name (version), size, and CRC32 of MCU FW downloaded to SFLASH.
UINT ota_update_read_mcu_fw(UINT sflash_addr, UINT size)		
Parameter	[in] sflash_addr [int] size	sflash_addr Start address for reading. Read size.
Return		Returns 0x00 on success. See Table 31.
Description		Starts transmission of MCU FW stored in flash through interface as much as the set size.
UINT ota_update_trans_mcu_fw(void)		
Parameter	void	None.
Return		Returns 0x00 on success. See Table 31.
Description		Starts transmission of MCU FW stored in flash through interface.
UINT ota_update_erase_mcu_fw(void)		
Parameter	void	None.
Return		Returns 0x00 on success. See Table 31.
Description		Deletes MCU FW saved in SFLASH.
UINT ota_update_calcu_mcu_fw_crc(int sflash_addr, int size)		
Parameter	[in] sflash_addr [int] size	sflash_addr CRC calculation start address. CRC calculation size.
Return		Returns 0x00 on success. See Table 31.
Description		Calculates CRC32 of MCU FW stored in SFLASH.

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Item		Description
UINT ota_update_set_tls_auth_mode_nvram(int tls_auth_mode);		
Parameter	[in] tls_auth_mode	Set the certificate verification mode. #define MBEDTLS_SSL_VERIFY_NONE 0 #define MBEDTLS_SSL_VERIFY_OPTIONAL 1 #define MBEDTLS_SSL_VERIFY_REQUIRED 2
Return		Returns 0x00 on success. See Table 31.
Description		Initialize interface to transfer firmware between DA16x and MCU.

13.5.4 Example

This is an example of DA16200 firmware update.

1. Make sure to set update type to OTA_TYPE_RTOS.

   /* Setting the type to be updated */

   g_ota_update_conf->update_type = OTA_TYPE_RTOS;

2. Set URL to suit the user environment.

   /* URL setting example - Change it to suit your environment. */

   memcpy(g_ota_update_conf->url, ota_server_url_rtos, strlen(ota_server_url_rtos));

3. If the download completes successfully, the user can set it to automatically activate RENEW.

   g_ota_update_conf->auto_renew = 1;

4. By registering a callback function in download_notify, the user can be notified whether the download succeeds or fails. Users can check whose notification is by update_type.

   g_ota_update_conf->download_notify = user_sample_da16_fw_download_notify;

5. Receive notification about the RENEW status by registering a callback function. If the notification status is successful, the DA16200 automatically reboots after 2-3 seconds.

   g_ota_update_conf->renew_notify = user_sample_da16_fw_renew_notify;

6. Finally, call the OTA update start API. When ota_update_start_download() is called, an OTA update task is created internally and the creation status of the task is immediately returned. The process is not blocked.

   status = ota_update_start_download(g_ota_update_conf);

7. Reboot DA16200 when the firmware updated.

13.5.4.1 Test Command

The DA16200/DA16600 SDK includes sample codes and CLI commands to make it easier for users to use the OTA update. It is possible to program directly by referring to the sample code, but the user can simply check the network status with the OTA server by using the CLI command before that.

- Download Example Using CLI Command

```
[/DA16200/NET] # ota_update rtos https://ota-server/NEW_RTOS.img
  > Server FW version: RTOS-GEN01-01-12345-000000
  >> HTTP(s) Client Downloading... 100 % (800000/800000 Bytes)
- OTA Update: <RTOS> Download – Success
[/DA16200/NET] # ota_update renew
```

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Table 35: OTA Test Command

Command		Option	Description
ota_update		[update_type] [url]	Start to FW download. * update_type rtos: update_type of RTOS cert_key: update_type of cert or key. mcu_fw: update_type of MCU FW. url: Server URL where FW exists ex) ota_update rtos http://192.168.0.1/rtos.img
	stop		Stop to firmware download. ex) ota_update stop
	renew		Change current firmware to new firmware. ex) ota_update renew
	info		Show FW information. ex) ota_update info
	crc	[addr]	Check CRC of firmware. ex) ota_update crc 0x1e2000
	read_sflash	[addr] [size]	Read sflash data. ex) ota_update read_sflash 0x1e2000 128
	copy_sflash	[dst_addr] [src_addr] [size]	Copy from sflash data src_add to dst_add. ex) ota_update copy_sflash 0x3ad000 0x1e2000 4096
	erase_sflash	[addr] [size]	Erase sflash data. ex) ota_update erase_sflash 0x3ad000 4096
	set_name_mcu		Set the name (version) of MCU FW to be downloaded to sflash. ex) ota_update set_name_mcu MCU_FW
	get_name_mcu		Get name (version) of MCU FW downloaded to sflash. ex) ota_update get_name_mcu
	read_mcu		Read the firmware as much as the size from the read_addr and transmit it. ex) ota_update read_sflash 0x3ad000 4096
	trans_mcu		Transmit a firmware to MCU through interface. ex) ota_update trans_mcu
	erase_mcu		Erase the firmware stored in a serial flash of DA16200/DA16600. ex) ota_update erase_mcu
	get_boot_index		Get current boot index info. ex) ota_update get_boot_index
	toggle_boot_index		Toggle boot index. ex) ota_update toggle_boot_index

13.5.4.2 Sample Code

The DA16200/DA16600 SDK provides sample code and user guide:

- Sample code

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The sample code includes not only the DA16200/DA16600 firmware update, but also a sample of the MCU firmware and certificate update.

.\sample\Network\OTA_Update\src\ota_update_sample.c

13.6 OTA Firmware Update - Extensions

The OTA firmware update supports updating not only the DA16200/DA16600 firmware but also the firmware of the MCU chip or the certificate for TLS protocol.

13.6.1 Certificates

To update the SFLASH *TLS Certificate #1* and *TLS Certificate #2* areas:

Download directly to SFLASH *TLS Certificate #1, TLS Certificate #2*, or User Area and copy to SFLASH *TLS Certificate #1* or *TLS Certificate #2*.

1. Set URL to suit the user environment.

   /* URL setting example - Change it to suit your environment. */

   memcpy(g_ota_update_conf->url, ota_server_url_cert, strlen(ota_server_url_cert));
2. Make sure to set update_type to OTA_TYPE_CERT_KEY.

   g_ota_update_conf->update_type = OTA_TYPE_CERT_KEY;
3. Set the address of SFLASH to be saved when downloading. If not set, the default is SFLASH_USER_AREA_0_START. (See Table 30)

   g_ota_update_conf->download_sflash_addr = SFLASH_USER_AREA_0_START;
4. Register a callback to be notified of the download status.

   g_ota_update_conf->download_notify = user_sample_cert_key_download_notify;
5. Finally, call the OTA update start API. When ota_update_start_download() is called, an OTA update task is created internally and the creation status of the task is immediately returned. The process is not blocked.

   status = ota_update_start_download(g_ota_update_conf);
6. Copy them to the TLS Certificate Key #0 and TLS Certificate Key #1 areas when downloaded.

   status = ota_update_copy_flash(SFLASH_ROOT_CA_ADDR1, g_ota_update_conf->download_sflash_addr, 4096);

13.6.2 MCU Firmware

To update the firmware of the MCU connected to the DA16200/DA16600 interface:

1. Set URL to suit the user environment.

   /* URL setting example - Change it to suit your environment. */

   memcpy(g_ota_update_conf->url, ota_server_url_mcu, strlen(ota_server_url_mcu));
2. Set update_type to OTA_TYPE_MCU_FW.

   g_ota_update_conf->update_type = OTA_TYPE_MCU_FW;
3. Set the address of SFLASH to save when downloading. If not set, the default is SFLASH_USER_AREA_0_START. (See Table 30)

   g_ota_update_conf->download_sflash_addr = SFLASH_USER_AREA_0_START;
4. Register a callback to notify the download status.

   g_ota_update_conf->download_notify = user_sample_mcu_fw_download_notify;
5. Call the OTA update start API. When ota_update_start_download() is called, an OTA update task is created internally and the creation status of the task is immediately returned. The process is not blocked.

   status = ota_update_start_download(g_ota_update_conf);
6. Transmit the firmware to the MCU when downloaded.

   When the transmission API is called, transmit <FW_NAME>, <FW_SIZE>, <FW_CRC> information to the MCU first. Next, transmit the divided buffer size of the entire firmware the MCU.

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That is, transmit "MCU_FW,4096,5aa8b6c4" to the MCU first. Then, transmit 2048 bytes, the divided buffer size of the firmware (4096 divided by 2), to the MCU in sequential order as shown in Figure 94.

Note that buffer size is defined by OTA_MCU_BUF_SIZE.

```
ota_update_trans_mcu_fw();
```

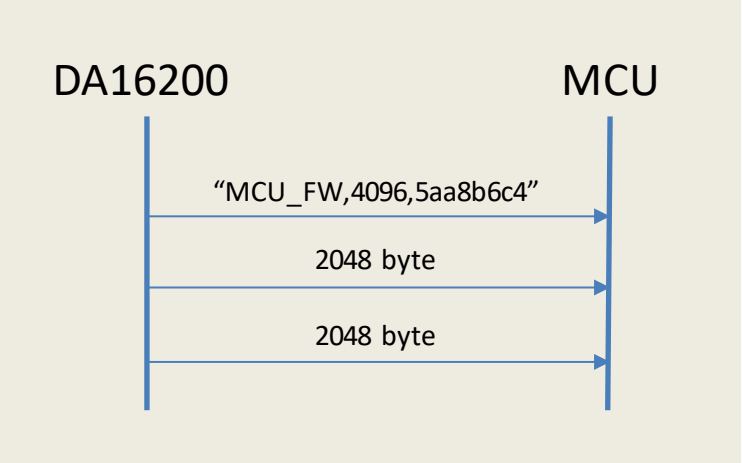

Figure 94: MCU Firmware

13.6.2.1 CRC-32 Calculation

This is an example for calculating the CRC value required in the Transfer protocol.

```
static const unsigned int ota_crc_table[] =
{
  0x00000000L, 0x77073096L, 0xee0e612cL, 0x990951baL, 0x076dc419L,
  0x706af48fL, 0xe963a535L, 0x9e6495a3L, 0x0edb8832L, 0x79dcb8a4L,
  0xe0d5e91eL, 0x97d2d988L, 0x09b64c2bL, 0x7eb17cbdL, 0xe7b82d07L,
  0x90bf1d91L, 0x1db71064L, 0x6ab020f2L, 0xf3b97148L, 0x84be41deL,
  0x1adad47dL, 0x6ddde4ebL, 0xf4d4b551L, 0x83d385c7L, 0x136c9856L,
  0x646ba8c0L, 0xfd62f97aL, 0x8a65c9ecL, 0x14015c4fL, 0x63066cd9L,
  0xfa0f3d63L, 0x8d080df5L, 0x3b6e20c8L, 0x4c69105eL, 0xd56041e4L,
  0xa2677172L, 0x3c03e4d1L, 0x4b04d447L, 0xd20d85fdL, 0xa50ab56bL,
  0x35b5a8faL, 0x42b2986cL, 0xdbbbc9d6L, 0xacbcf940L, 0x32d86ce3L,
  0x45df5c75L, 0xdcd60dcfL, 0xabd13d59L, 0x26d930acL, 0x51de003aL,
  0xc8d75180L, 0xbfd06116L, 0x21b4f4b5L, 0x56b3c423L, 0xcfba9599L,
  0xb8bda50fL, 0x2802b89eL, 0x5f058808L, 0xc60cd9b2L, 0xb10be924L,
  0x2f6f7c87L, 0x58684c11L, 0xc1611dabL, 0xb6662d3dL, 0x76dc4190L,
  0x01db7106L, 0x98d220bcL, 0xefd5102aL, 0x71b18589L, 0x06b6b51fL,
  0x9fbfe4a5L, 0xe8b8d433L, 0x7807c9a2L, 0x0f00f934L, 0x9609a88eL,
  0xe10e9818L, 0x7f6a0dbbL, 0x086d3d2dL, 0x91646c97L, 0xe6635c01L,
  0x6b6b51f4L, 0x1c6c6162L, 0x856530d8L, 0xf262004eL, 0x6c0695edL,
  0x1b01a57bL, 0x8208f4c1L, 0xf50fc457L, 0x65b0d9c6L, 0x12b7e950L,
  0x8bbeb8eaL, 0xfcb9887cL, 0x62dd1ddfL, 0x15da2d49L, 0x8cd37cf3L,
  0xfbd44c65L, 0x4db26158L, 0x3ab551ceL, 0xa3bc0074L, 0xd4bb30e2L,
  0x4adfa541L, 0x3dd895d7L, 0xa4d1c46dL, 0xd3d6f4fbL, 0x4369e96aL,
  0x346ed9fcL, 0xad678846L, 0xda60b8d0L, 0x44042d73L, 0x33031de5L,
  0xaa0a4c5fL, 0xdd0d7cc9L, 0x5005713cL, 0x270241aaL, 0xbe0b1010L,
  0xc90c2086L, 0x5768b525L, 0x206f85b3L, 0xb966d409L, 0xce61e49fL,
  0x5edef90eL, 0x29d9c998L, 0xb0d09822L, 0xc7d7a8b4L, 0x59b33d17L,
  0x2eb40d81L, 0xb7bd5c3bL, 0xc0ba6cadL, 0xedb88320L, 0x9abfb3b6L,
  0x03b6e20cL, 0x74b1d29aL, 0xead54739L, 0x9dd277afL, 0x04db2615L,
  0x73dc1683L, 0xe3630b12L, 0x94643b84L, 0x0d6d6a3eL, 0x7a6a5aa8L,
```

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```
  0xe40ecf0bL, 0x9309ff9dL, 0x0a00ae27L, 0x7d079eb1L, 0xf00f9344L,
  0x8708a3d2L, 0x1e01f268L, 0x6906c2feL, 0xf762575dL, 0x806567cbL,
  0x196c3671L, 0x6e6b06e7L, 0xfed41b76L, 0x89d32be0L, 0x10da7a5aL,
  0x67dd4accL, 0xf9b9df6fL, 0x8ebeeff9L, 0x17b7be43L, 0x60b08ed5L,
  0xd6d6a3e8L, 0xa1d1937eL, 0x38d8c2c4L, 0x4fdff252L, 0xd1bb67f1L,
  0xa6bc5767L, 0x3fb506ddL, 0x48b2364bL, 0xd80d2bdaL, 0xaf0a1b4cL,
  0x36034af6L, 0x41047a60L, 0xdf60efc3L, 0xa867df55L, 0x316e8eefL,
  0x4669be79L, 0xcb61b38cL, 0xbc66831aL, 0x256fd2a0L, 0x5268e236L,
  0xcc0c7795L, 0xbb0b4703L, 0x220216b9L, 0x5505262fL, 0xc5ba3bbeL,
  0xb2bd0b28L, 0x2bb45a92L, 0x5cb36a04L, 0xc2d7ffa7L, 0xb5d0cf31L,
  0x2cd99e8bL, 0x5bdeae1dL, 0x9b64c2b0L, 0xec63f226L, 0x756aa39cL,
  0x026d930aL, 0x9c0906a9L, 0xeb0e363fL, 0x72076785L, 0x05005713L,
  0x95bf4a82L, 0xe2b87a14L, 0x7bb12baeL, 0x0cb61b38L, 0x92d28e9bL,
  0xe5d5be0dL, 0x7cdcefb7L, 0x0bdbdf21L, 0x86d3d2d4L, 0xf1d4e242L,
  0x68ddb3f8L, 0x1fda836eL, 0x81be16cdL, 0xf6b9265bL, 0x6fb077e1L,
  0x18b74777L, 0x88085ae6L, 0xff0f6a70L, 0x66063bcaL, 0x11010b5cL,
  0x8f659effL, 0xf862ae69L, 0x616bffd3L, 0x166ccf45L, 0xa00ae278L,
  0xd70dd2eeL, 0x4e048354L, 0x3903b3c2L, 0xa7672661L, 0xd06016f7L,
  0x4969474dL, 0x3e6e77dbL, 0xaed16a4aL, 0xd9d65adcL, 0x40df0b66L,
  0x37d83bf0L, 0xa9bcae53L, 0xdebb9ec5L, 0x47b2cf7fL, 0x30b5ffe9L,
  0xbdbdf21cL, 0xcabac28aL, 0x53b39330L, 0x24b4a3a6L, 0xbad03605L,
  0xcdd70693L, 0x54de5729L, 0x23d967bfL, 0xb3667a2eL, 0xc4614ab8L,
  0x5d681b02L, 0x2a6f2b94L, 0xb40bbe37L, 0xc30c8ea1L, 0x5a05df1bL,
  0x2d02ef8dL

};


/* update the CRC on the data block one byte at a time */

static unsigned int update_crc (unsigned int init, const unsigned char *buf,
int len)

{

       unsigned int crc = init;

       while (len--)

              crc = ota_crc_table[(crc ^ *(buf++)) & 0xFF] ^ (crc >> 8);

       return ~crc;

}
```

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13.7 BLE Firmware Update OTA

After building the code of the DA14531 SDK, the following images are available to update DA14531 firmware via the OTA. See Ref. [3] for details.

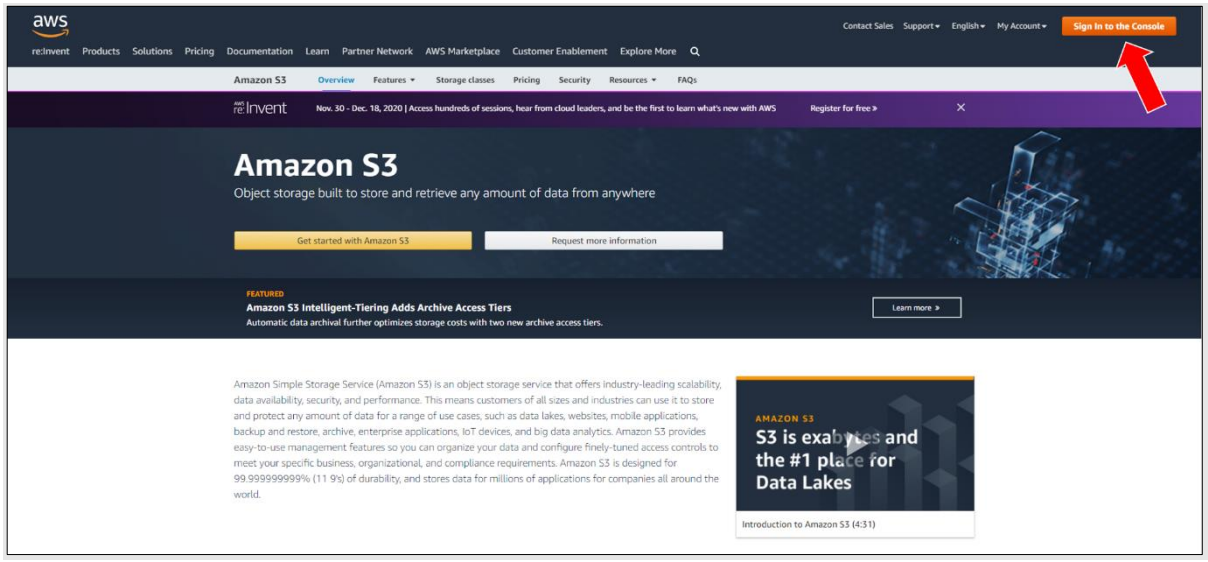
- The DA14531 SDK.
  [DA16600 SDK ROOT]\utility\combo\da14531_sdk_v_6.0.14.1114.zip
- The BLE OTA firmware images for the DA16600 examples (after code build):
  - IoT Sensor gateway example (central example)
    [DA14531_SDK_ROOT]\projects\target_apps\ble_examples\prox_monitor_aux_ext_coex\Keil_5\out_img\px**m**_coex_ext_531_6_0_14_1_ota.img.
  - Rest of the DA16600 examples (peripheral examples)
    [DA14531_SDK_ROOT]\projects\target_apps\ble_examples\prox_reporter_sensor_ext_coex\Keil_5\out_img\px**r**_sr_coex_ext_531_6_0_14_1114_1_**ota**.img.

13.8 OTA Test Server

OTA update complies with HTTP protocol to download firmware. Therefore, users can easily implement an OTA server using HTTP-server. This manual does not provide a guide on configuring OTA servers. However, it explains how to configure a simple test environment for functional testing in the application development stage on the cloud environment.

Amazon Simple Storage Service (Amazon S3) is recommended for the OTA test server.

8. Sign up for an AWS account and log in to the console.



9. In the AWS console, go to **Storage** and choose **S3**.

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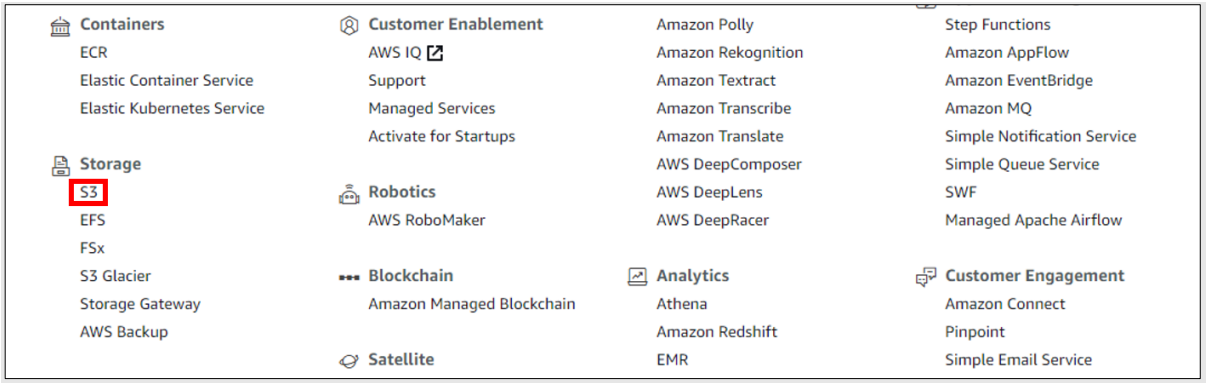
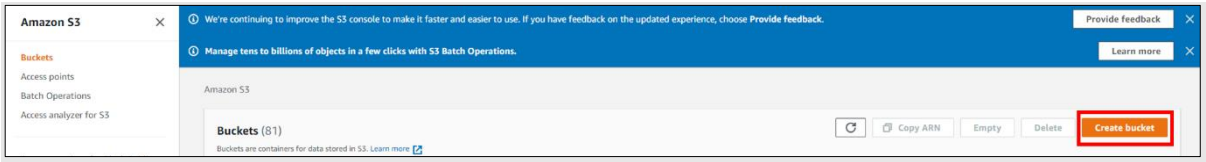
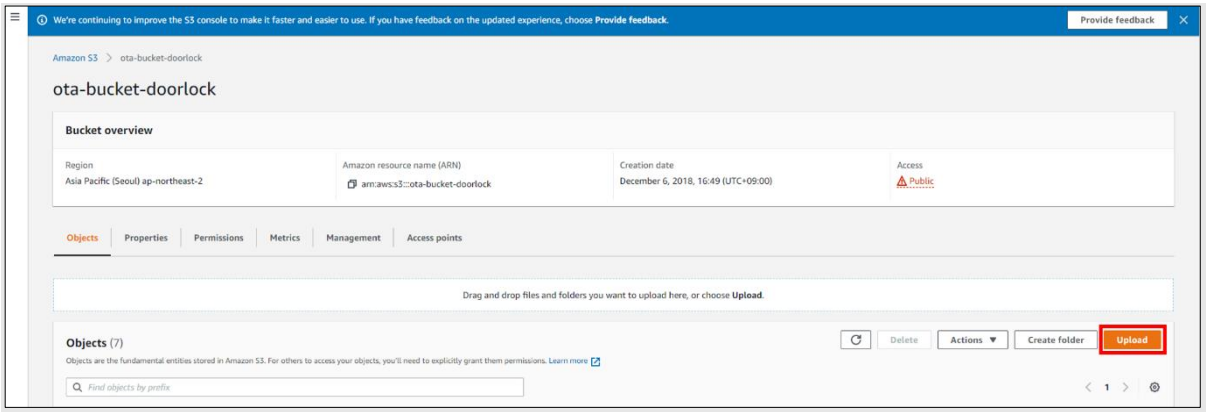


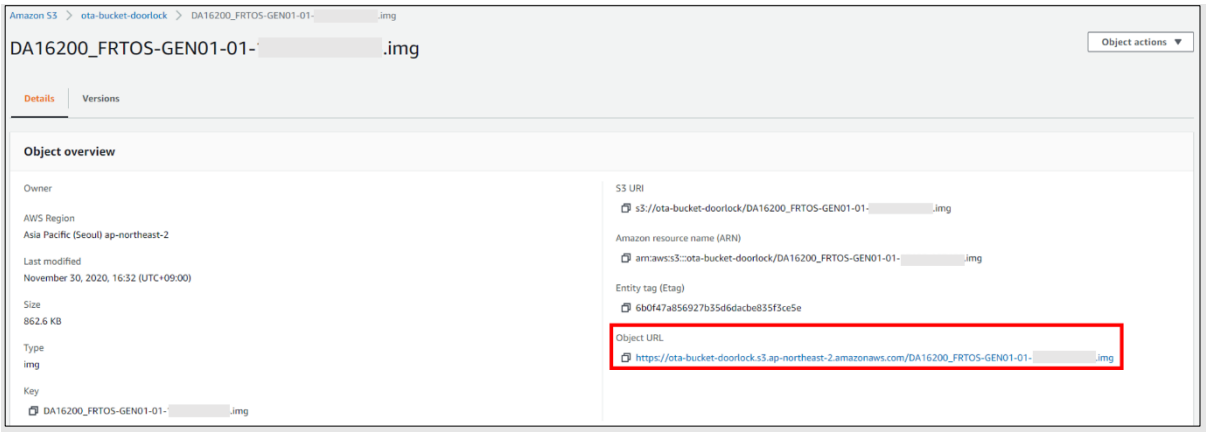
10. To create a bucket with default settings, click **Create Bucket**.



11. Upload the firmware to the created bucket.



12. Check the URL (https://) of the uploaded firmware.



13. Set the URL as the OTA update API parameter value and proceed with the test.

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Additional Examples

14.1 RTC Timer in DPM

This sample code describes how to use the RTC timer for wakeup from Sleep mode 2 or Sleep mode 3 and, see Ref. [2] for further details.

14.1.1 How to Run

1. In the e²studio, import a project for the RTC timer sample application as follows:
   a. *~/SDK/apps/common/examples/Peripheral/RTC_Timer_DPM/projects/da16200*
2. Build the DA16200 SDK, download the RTOS image to the DA16200 EVB, and reboot.
3. Use the console terminal of DA16200 EVB to set up the Wi-Fi station interface and enable DPM mode.
4. After reboot, the RTC timer sample application starts automatically.

   Note that the user can select Sleep modes in the sample code.

```
/* Defines for sample */
#undef   SAMPLE_FOR_DPM_SLEEP_2          // Sleep mode 2
#define  SAMPLE_FOR_DPM_SLEEP_3          // Sleep mode 3
```

14.1.2 Timer Creation: Sleep Mode 2

Sleep mode 2 powers off all components of DA16200 except RTC. However, for test purpose, retention memory can be powered on. External wake-up or RTC timer can wake up a DUT (Device Under Test) in Sleep mode 2. If the RTC timer is not set, the DUT in Sleep mode 2 is not woken up by the RTC timer. When the DUT has woken up by wake-up sources, it works using the data of retention memory.

To go to Sleep mode 2, just run API dpm_sleep_start_mode_2().

```
Void rtc_timer_sample(void * param)
{
    unsigned long long     wakeup_time;

    /* Just work in case of RTC timer wakeup */
    if ( dpm_mode_is_wakeup() == DPM_WAKEUP
          && dpm_get_wakeup_source() != WAKEUP_COUNTER_WITH_RETENTION) {
        dpm_app_sleep_ready_set(SAMPLE_RTC_TIMER);
        return;
    }

    /* TRUE : Maintain RTM area for DPM operation */
    wakeup_time = MICROSEC_FOR_ONE_SEC * RTC_TIMER_WAKEUP_ONCE;
    dpm_sleep_start_mode_2(wakeup_time, TRUE);
}
```

14.1.3 Timer Creation: Sleep Mode 3

Sleep mode 3 powers off all components except RTC, retention memory, and pTIM (should be in running state in order to be connected to Wi-Fi). Sleep mode 3 is always connected to the Wi-Fi, but Sleep mode 2 needs to connect to the Wi-Fi network first and transmits or receives data. For more detailed information on Sleep mode 3, see Ref. [4].

This sample code shows how to create the one-shot RTC timer and a periodic RTC timer.

```
void rtc_timer_sample(void * param)
{
    ULONG     status;
```

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```
    if (dpm_mode_is_wakeup() == NORMAL_BOOT) {

       /*
        * Create a timer only once during normal boot.
        */

       dpm_app_sleep_ready_clear(SAMPLE_RTC_TIMER);

       /* One-Shot timer */
       status = dpm_timer_create(SAMPLE_RTC_TIMER,
                            "timer1",
                             rtc_timer_dpm_once_cb,
                             RTC_TIMER_WAKEUP_ONCE,
                             0);
       switch ((int)status) {
         case DPM_MODE_NOT_ENABLED    :
         case DPM_TIMER_SEC_OVERFLOW :
         case DPM_TIMER_ALREADY_EXIST:
         case DPM_TIMER_NAME_ERROR    :
         case DPM_UNSUPPORTED_RTM     :
         case DPM_TIMER_REGISTER_FAIL:
         case DPM_TIMER_MAX_ERR :
             PRINTF(">>> Fail to create %s timer (err=%d)\n",
                    SAMPLE_CUR_TIME_DPM, (int)status);
             // Delay to display above message on console ...
             vTaskDelay(2);

             break;
       }

       /* Periodic timer */
       status = dpm_timer_create(SAMPLE_RTC_TIMER,
                            "timer2",
                            rtc_timer_dpm_periodic_cb,
                            RTC_TIMER_WAKEUP_PERIOD,
                            RTC_TIMER_WAKEUP_PERIOD);
       switch ((int)status) {
        case DPM_MODE_NOT_ENABLED    :
        case DPM_TIMER_SEC_OVERFLOW :
        case DPM_TIMER_ALREADY_EXIST:
        case DPM_TIMER_NAME_ERROR    :
        case DPM_UNSUPPORTED_RTM     :
        case DPM_TIMER_REGISTER_FAIL:
        case DPM_TIMER_MAX_ERR       :
            PRINTF(">> Fail to create %s timer (err=%d)\n",
                   SAMPLE_CUR_TIME_DPM, (int)status);

         // Delay to display above message on console ...
         vTaskDelay(2);

         break;
       }

       dpm_app_sleep_ready_set(SAMPLE_RTC_TIMER);
    } else {
       /* Notice initialize done to DPM module */
       dpm_app_wakeup_done(SAMPLE_RTC_TIMER);
    }

    while (1) {
```

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```
        /* Nothing to do... */
        vTaskDelay(100);
    }
}
```

14.2 Get SCAN Result Sample

14.2.1 How to Run

In the e²studio, import a project for the SCAN result sample application as follows:

- *~/SDK/apps/common/examples/ETC/Get_Scan_Result/projects/da16200*

1. Build the DA16200 SDK, download the RTOS image to the DA16200 EVB, and reboot.
2. After the boot is complete, the get_scan_result sample starts automatically.

Figure 95: Get_Scan_Result AP List

14.2.2 Sample Code

This sample shows how to use the void get_scan_result(void *user_buf_ptr) API and to get the SCAN result on STA mode and Soft AP mode.

14.2.2.1 Application Initialization

The get_scan_result_sample function executes after the basic FreeRTOS initialization is complete. This sample simply calls the user API “void get_scan_result()”.

```
void get_scan_result_sample(void * param)
{
    char      *user_buf = NULL;
    scan_result_t    *scan_result;
    int     i;

    /* Allocate buffer to get scan result */
    user_buf = pvPortMalloc(SCAN_RSP_BUF_SIZE);

    /* Get scan result */
    get_scan_result((void *) user_buf);

    … …
}
```

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14.2.2.2 Get SCAN Result

After running the API “get_scan_result()”, the user can use the received data. This sample code shows how to display the scan list in the console.

```
/* Display result on console */
scan_result = (scan_result_t *)user_buf;

PRINTF("\n>>> Scanned AP List (Total : %d) \n", scan_result->ssid_cnt);

for (i = 0; i < scan_result->ssid_cnt; i++) {
    PRINTF(" %02d) SSID: %s, RSSI: %d, Security: %d\n",
                i + 1,
                scan_result->scanned_ap_info[i].ssid,
                scan_result->scanned_ap_info[i].rssi,
                scan_result->scanned_ap_info[i].auth_mode) ;
}

/* Buffer free */
vPortFree(user_buf);
```

The SCAN results are stored in the following data structure format:

```
typedef struct scanned_ap_info {
    int       auth_mode;
    int       rssi;
    char      ssid[128];
} scanned_ap_info_t;

typedef struct scan_result_to_app {
    int       ssid_cnt;
    scanned_ap_info_t      scanned_ap_info[MAX_SCAN_AP_CNT];
} scan_result_t;
```

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15 Crypto Examples

15.1 Crypto API

This section describes how it is built and works. The Crypto API sample application demonstrates common use cases of cryptographic algorithms such as AES, DES, and Hash. The DA16200 SDK includes an "mbedTLS" library which is an implementation of the TLS and SSL protocols and the respective cryptographic algorithms.

15.1.1 How to Run

1. In the e²studio, import a project for the Crypto API sample application as follows:
   - *~/SDK/apps/common/examples/Crypto/Crypto_API/projects/da16200*
2. Enable features of what cryptographic algorithms are required.
3. Build the DA16200 SDK, download the RTOS image to the DA16200 EVB, and reboot.

15.1.2 How to Enable Cryptographic Algorithm

The Crypto API sample application includes 11 types of cryptographic algorithms. Each type can be enabled by feature definition in crypto_sample.h file as follows. By default, AES cryptographic algorithm is enabled.

- AES Algorithms
- Cipher API
- DES Algorithms
- Diffie-Hellman Key Exchange
- DRBG
- ECDH
- ECDSA
- HASH and HMAC Algorithms
- Key Derivation Function
- Public Key Abstraction Layer
- RSA PKCS#1

```
// AES Algorithms
#define __CRYPTO_SAMPLE_AES__

// Cipher API
#undef  __CRYPTO_SAMPLE_CIPHER__

// DES Algorithms
#undef  __CRYPTO_SAMPLE_DES__

// Diffie-Hellman key exchange
#undef  __CRYPTO_SAMPLE_DHM__

// DRBG
#undef  __CRYPTO_SAMPLE_DRBG__

// ECDH
#undef  __CRYPTO_SAMPLE_ECDH__

// ECDSA
#undef  __CRYPTO_SAMPLE_ECDSA__
```

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```
// Hash & HMAC Algorithms
#undef  __CRYPTO_SAMPLE_HASH__

// Key Derivation Function
#undef  __CRYPTO_SAMPLE_KDF__

// Public Key abstraction layer.
#undef  __CRYPTO_SAMPLE_PK__

// RSA PKCS#1
#undef  __CRYPTO_SAMPLE_RSA__
```

15.1.3 Cryptographic Algorithms – AES

The AES algorithm sample application demonstrates common use cases of AES ciphers such as CBC, CFB, and ECB. The sample application runs five types of cryptographic algorithms:

- AES-CBC-128, 192, and 256
- AES-CFB128-128, 192, and 256
- AES-ECB-128, 192, and 256
- AES-ECB-128, 192, and 256
- AES-CTR-128
- AES-CCM

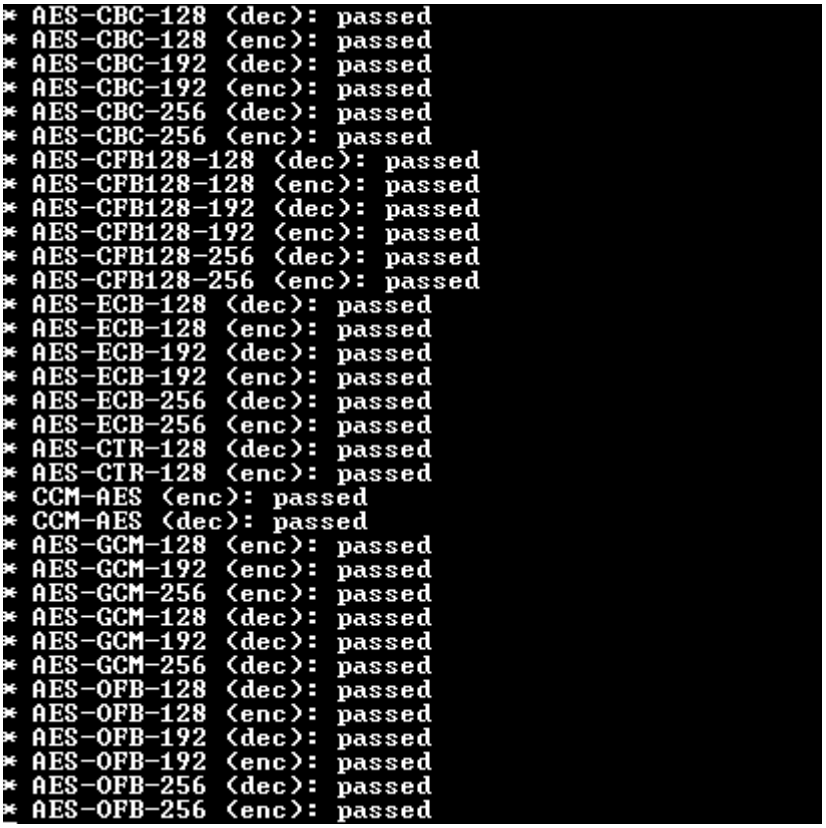

Figure 96: The Result of the Crypto AES

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15.1.3.1 Application Initialization

The example below describes how the user uses the AES algorithms of the “mbedTLS” library to encrypt and decrypt data.

```
void crypto_sample_aes(void *param)
{
#if defined(MBEDTLS_CIPHER_MODE_CBC)
    crypto_sample_aes_cbc();
#endif // (MBEDTLS_CIPHER_MODE_CBC)

#if defined(MBEDTLS_CIPHER_MODE_CFB)
    crypto_sample_aes_cfb();
#endif // (MBEDTLS_CIPHER_MODE_CFB)

    crypto_sample_aes_ecb();

#if defined(MBEDTLS_CIPHER_MODE_CTR)
    crypto_sample_aes_ctr();
#endif // (MBEDTLS_CIPHER_MODE_CTR)

    crypto_sample_aes_ccm();
    crypto_sample_aes_gcm();

#if defined(MBEDTLS_CIPHER_MODE_OFB)
    crypto_sample_aes_ofb();
#endif // (MBEDTLS_CIPHER_MODE_OFB)

    return ;
}
```

15.1.3.2 AES-CBC-128, 192, and 256

DA16200 supports cryptographic algorithm for AES-CBC-128, 192, and 256. To explain how AES-CBC works, see the test vector in http://csrc.nist.gov/archive/aes/rijndael/rijndael-vals.zip.

```
int crypto_sample_aes_cbc()
{
    mbedtls_aes_context *ctx = NULL;

    // Initialize the AES context.
    mbedtls_aes_init(ctx);

    for (i = 0; i < 6; i++) {
        u = i >> 1;
        v = i  & 1;

        PRINTF("* AES-CBC-%3d (%s): ", 128 + u * 64,
               (v == MBEDTLS_AES_DECRYPT) ? "dec" : "enc");

        if (v == MBEDTLS_AES_DECRYPT) {
            // Set the decryption key.
            mbedtls_aes_setkey_dec(ctx, key, 128 + u * 64);

            // Performs an AES-CBC decryption operation on full blocks.
            for (j = 0; j < CRYPTO_SAMPLE_AES_LOOP_COUNT ; j++) {
                mbedtls_aes_crypt_cbc(ctx, v, 16, iv, buf, buf);
            }
        } else {
            // Set the encryption key.
            mbedtls_aes_setkey_enc(ctx, key, 128 + u * 64);
```

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```
            // Performs an AES-CBC encryption operation on full blocks.
            for (j = 0 ; j < CRYPTO_SAMPLE_AES_LOOP_COUNT ; j++) {
                unsigned char tmp[16] = {0x00,};
                mbedtls_aes_crypt_cbc(ctx, v, 16, iv, buf, buf);

                memcpy(tmp, prv, 16);
                memcpy(prv, buf, 16);
                memcpy(buf, tmp, 16);
            }
        }
    }

    // Clear the AES context.
    mbedtls_aes_free(ctx);
}
```

The mbedtls_aes_context is the AES context-type definition to use the AES algorithm. It is initialized by function mbedtls_aes_init. Function mbedtls_aes_crypt_cbc does an AES-CBC encryption or decryption operation on full blocks. And it does the operation defined in the mode parameter (encrypt/decrypt), on the input data buffer defined in the input parameter. To do encryption or decryption, function mbedtls_aes_setkey_enc or mbedtls_aes_setkey_dec should be called first. After the operation is complete, function mbedtls_aes_free should be called to clear the AES context.

15.1.3.3 AES-CFB128-128, 192, and 256

DA16200 supports a cryptographic algorithm for AES-CFB128-128, 192, and 256. To explain how AES-CFB128 works, see the test vector in http://csrc.nist.gov/publications/nistpubs/800-38a/sp800-38a.pdf.

```
int crypto_sample_aes_cfb()
{
    mbedtls_aes_context *ctx = NULL;

    // Initialize the AES context.
    mbedtls_aes_init(ctx);

    for (i = 0; i < 6; i++) {
        u = i >> 1;
        v = i  & 1;

        PRINTF("* AES-CFB128-%3d (%s): ", 128 + u * 64,
                (v == MBEDTLS_AES_DECRYPT) ? "dec" : "enc");

        // Set the key.
        mbedtls_aes_setkey_enc(ctx, key, 128 + u * 64);

        if (v == MBEDTLS_AES_DECRYPT) {
            // Perform an AES-CFB128 decryption operation.
            mbedtls_aes_crypt_cfb128(ctx, v, 64, &offset, iv, buf, buf);
        } else {
            // Perform an AES-CFB128 encryption operation.
            mbedtls_aes_crypt_cfb128(ctx, v, 64, &offset, iv, buf, buf);
        }
    }

    // Clear the AES context.
    mbedtls_aes_free(ctx);
}
```

The mbedtls_aes_context is the AES context-type definition to use the AES algorithm. It is initialized by function mbedtls_aes_init. Function mbedtls_aes_crypt_cfb128 does AES-CFB128 encryption or decryption. And it does the operation defined in the mode parameter (encrypt or decrypt) on the input

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data buffer defined in the input parameter. For CFB, the user should set up the context with function mbedtls_aes_setkey_enc, regardless of whether to encrypt or decrypt operations, that is, regardless of the mode parameter. This is because CFB mode uses the same key schedule for encryption and decryption. After the operation is complete, function mbedtls_aes_free should be called to clear the AES context.

15.1.3.4 AES-ECB-128, 192, and 256

DA16200 supports cryptographic algorithms for AES-ECB-128, 192, and 256. To explain how AES-ECB works, see the test vector in http://csrc.nist.gov/archive/aes/rijndael/rijndael-vals.zip.

```
int crypto_sample_aes_ecb()
{
    mbedtls_aes_context *ctx = NULL;

    // Initialize the AES context.
    mbedtls_aes_init(ctx);

    for (i = 0; i < 6; i++) {
        u = i >> 1;
        v = i  & 1;

        PRINTF("* AES-ECB-%3d (%s): ", 128 + u * 64,
                 (v == MBEDTLS_AES_DECRYPT) ? "dec" : "enc");

        if (v == MBEDTLS_AES_DECRYPT) {
            // Set the decryption key.
            mbedtls_aes_setkey_dec(ctx, key, 128 + u * 64);

            // Perform an AES single-block decryption operation.
            for (j = 0 ; j < CRYPTO_SAMPLE_AES_LOOP_COUNT ; j++) {
                mbedtls_aes_crypt_ecb(ctx, v, buf, buf);
            }
        } else {
            // Set the encryption key.
            mbedtls_aes_setkey_enc(ctx, key, 128 + u * 64);

            // Perform an AES single-block encryption operation.
            for (j = 0 ; j < CRYPTO_SAMPLE_AES_LOOP_COUNT ; j++) {
                mbedtls_aes_crypt_ecb(ctx, v, buf, buf);
            }
        }
    }

    // Clear the AES context.
    mbedtls_aes_free(ctx);
}
```

The mbedtls_aes_context is the AES context-type definition to use the AES algorithm. It is initialized by function mbedtls_aes_init. Function mbedtls_aes_crypt_ecb does an AES single-block encryption or decryption operation. And it does the operation defined in the mode parameter (encrypt or decrypt) on the input data buffer defined in the input parameter. Function mbedtls_aes_init and either function mbedtls_aes_setkey_enc function or function mbedtls_aes_setkey_dec should be called before the first call to this API with the same context. After the operation is complete, function mbedtls_aes_free should be called to clear the AES context.

15.1.3.5 AES-CTR-128

DA16200 supports cryptographic algorithms for AES-CTR-128. To explain how AES-CTR works, see the Test Vectors section in http://www.faqs.org/rfcs/rfc3686.html.

```
int crypto_sample_aes_ctr()
```

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```
{
    mbedtls_aes_context *ctx = NULL;

    // Initialize the AES context.
    mbedtls_aes_init(ctx);

    for (i = 0; i < 2; i++) {
        v = i  & 1;

        PRINTF("* AES-CTR-128 (%s): ",
                    (v == MBEDTLS_AES_DECRYPT) ? "dec" : "enc");

        // Set the key.
        mbedtls_aes_setkey_enc(ctx, key, 128);

        if (v == MBEDTLS_AES_DECRYPT) {
            // Perform an AES-CTR decryption operation.
            mbedtls_aes_crypt_ctr(ctx, len, &offset,
                                  nonce_counter, stream_block, buf, buf);

        } else {
            // Perform an AES-CTR encryption operation.
            mbedtls_aes_crypt_ctr(ctx, len, &offset,
                                  nonce_counter, stream_block, buf, buf);
        }
    }

    // Clear the AES context.
    mbedtls_aes_free(ctx);
}
```

The mbedtls_aes_context is the AES context-type definition to use the AES algorithm. It is initialized by function mbedtls_aes_init. Function mbedtls_aes_crypto_ctr does an AES-CTR encryption or decryption operation. And it does the operation defined in the mode parameter (encrypt/decrypt) on the input data buffer, defined in the input parameter. Due to the nature of CTR, use the same key schedule for both encryption and decryption operations. Therefore, use the context initialized with function mbedtls_aes_setkey_enc for both MBEDTLS_AES_ENCRYPT and MBEDTLS_AES_DECRYPT. After the operation is complete, call function mbedtls_aes_free to clear the AES context.

15.1.3.6 AES-CCM-128, 192, and 256

DA16200 supports cryptographic algorithms for AES-CCM-128, 192, and 256. To explain how AES-CCM works, see the test vector in SP800-38C Appendix C #1.

```
int crypto_sample_aes_ccm()
{
    mbedtls_ccm_context *ctx = NULL;

    // Initialize the CCM context
    mbedtls_ccm_init(ctx);

    /* Initialize the CCM context set in the ctx parameter
    * and sets the encryption key.
    */

    ret = mbedtls_ccm_setkey(ctx, MBEDTLS_CIPHER_ID_AES,
                             crypto_sample_ccm_key,
                             8 * sizeof(crypto_sample_ccm_key));
    PRINTF("* CCM-AES (enc): ");
```

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```
    // Encrypt a buffer using CCM.
    ret = mbedtls_ccm_encrypt_and_tag(ctx, crypto_sample_ccm_msg_len,
                                      crypto_sample_ccm_iv, crypto_sample_ccm_iv_len,
                                      crypto_sample_ccm_ad, crypto_sample_ccm_add_len,
                                      crypto_sample_ccm_msg, out,
                                      out + crypto_sample_ccm_msg_len,
                                      crypto_sample_ccm_tag_len);

    PRINTF("* CCM-AES (dec): ");

    // Perform a CCM* authenticated decryption of a buffer.
    ret = mbedtls_ccm_auth_decrypt(ctx, crypto_sample_ccm_msg_len,
                                   crypto_sample_ccm_iv, crypto_sample_ccm_iv_len,
                                   crypto_sample_ccm_ad, crypto_sample_ccm_add_len,
                                   crypto_sample_ccm_res, out,
                                   crypto_sample_ccm_res + crypto_sample_ccm_msg_len,
                                   crypto_sample_ccm_tag_len);

    // Clear the CCM context.
    mbedtls_ccm_free(ctx);
}
```

The mbedtls_ccm_context is the CCM context-type definition for the CCM authenticated encryption mode for block ciphers. It is initialized by function mbedtls_ccm_init. Function mbedtls_ccm_setkey initializes the CCM context set in the ctx parameter and sets the encryption key. Function mbedtls_ccm_encrypt_and_tag encrypts a buffer with CCM. And function mbedtls_ccm_auth_decrypt does CCM-authenticated decryption of a buffer. After the operation is complete, call function mbed_ccm_free to release and clear the specified CCM context and underlying cipher subcontext.

15.1.3.7 AES-GCM-128, 192, and 256

DA16200 supports cryptographic algorithms for AES-GCM-128, 192, and 256. To explain how AES-GCM works, see the test vector in the GCM test vectors of CSRC (http://csrc.nist.gov/groups/STM/cavp/documents/mac/gcmtestvectors.zip).

```
int crypto_sample_aes_gcm()
{
    //The GCM context structure.
    mbedtls_gcm_context *ctx = NULL;
    mbedtls_cipher_id_t cipher = MBEDTLS_CIPHER_ID_AES;

    // Initialize the specified GCM context.
    mbedtls_gcm_init(ctx);

    // AES-GCM Encryption Test
    for (j = 0; j < 3; j++) {
        int key_len = 128 + 64 * j;

        PRINTF("* AES-GCM-%3d (%s): ", key_len, "enc");

        // Associate a GCM context with a cipher algorithm and a key.
        mbedtls_gcm_setkey(ctx, cipher, crypto_sample_gcm_key, key_len);

        // Perform GCM encryption of a buffer.
        ret = mbedtls_gcm_crypt_and_tag(ctx, MBEDTLS_GCM_ENCRYPT,
                                        sizeof(crypto_sample_gcm_pt),
                                        crypto_sample_gcm_iv, sizeof(crypto_sample_gcm_iv),
                                        crypto_sample_gcm_additional,
                                        sizeof(crypto_sample_gcm_additional),
                                        crypto_sample_gcm_pt, buf,
```

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```
                                16, tag_buf);

        // Clear a GCM context and the underlying cipher sub-context.
        mbedtls_gcm_free(ctx);
    }

    //AES-GCM Decryption Test
    for (j = 0; j < 3; j++) {
        int key_len = 128 + 64 * j;

        PRINTF("* AES-GCM-%3d (%s): ", key_len, "dec");

        // Associate a GCM context with a cipher algorithm and a key.
        mbedtls_gcm_setkey(ctx, cipher, crypto_sample_gcm_key, key_len);

        // Perform GCM decryption of a buffer.
        ret = mbedtls_gcm_crypt_and_tag(ctx, MBEDTLS_GCM_DECRYPT,
                                sizeof(crypto_sample_gcm_pt),
                                crypto_sample_gcm_iv, sizeof(crypto_sample_gcm_iv),
                                crypto_sample_gcm_additional,
                                sizeof(crypto_sample_gcm_additional),
                                crypto_sample_gcm_ct[j], buf,
                                16, tag_buf);

        // Clear a GCM context and the underlying cipher sub-context.
        mbedtls_gcm_free(ctx);
    }
}
```

The mbedtls_gcm_context is the GCM context-type definition. It is initialized by function mbedtls_gcm_init. Function mbedtls_gcm_setkey associates a GCM context with a cipher algorithm (AES) and a key. Function mbedtls_gcm_crypt_and_tag does GCM encryption or decryption of a buffer by the second parameter. After the operation is complete, function mbed_gcm_free should be called to clear a GCM context and underlying cipher sub-context.

15.1.3.8 AES-OFB-128, 192, and 256

DA16200 supports cryptographic algorithms for AES-OFB-128, 192, and 256. To explain how AES-OFB works, see the test vector in the OFB test vectors of CSRC (https://csrc.nist.gov/publications/detail/sp/800-38a/final).

```
int crypto_sample_aes_ofb()
{
    mbedtls_aes_context *ctx = NULL;

    // Initialize the AES context.
    mbedtls_aes_init(ctx);

    // Test OFB mode
    for (i = 0; i < 6; i++) {
        PRINTF("* AES-OFB-%3d (%s): ", keybits,
                (v == MBEDTLS_AES_DECRYPT) ? "dec" : "enc");

        memcpy(iv, crypto_sample_aes_ofb_iv, 16);
        memcpy(key, crypto_sample_aes_ofb_key[u], keybits / 8);

        // Set the encryption key.
        ret = mbedtls_aes_setkey_enc(ctx, key, keybits);

        if (v == MBEDTLS_AES_DECRYPT) {
            memcpy(buf, crypto_sample_aes_ofb_ct[u], 64);
            expected_out = crypto_sample_aes_ofb_pt;
```

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```
        } else {
            memcpy(buf, crypto_sample_aes_ofb_pt, 64);
            expected_out = crypto_sample_aes_ofb_ct[u];
        }

        // Perform an AES-OFB (Output Feedback Mode) encryption or decryption
        // operation.
        ret = mbedtls_aes_crypt_ofb(ctx, 64, &offset, iv, stream_block, buf, buf);
    }

    // Clear the AES context.
    mbedtls_aes_free(ctx);
}
```

The mbedtls_aes_context is the AES context-type definition to use the AES algorithm. It is initialized by function mbedtls_aes_init. Function mbedtls_aes_crypt_ofb does an AES-OFB (Output Feedback Mode) encryption or decryption operation. For OFB, the user should set up the context with the function mbedtls_aes_setkey_enc, regardless of whether the user does an encryption or decryption operation. This is because OFB mode uses the same key schedule for encryption and decryption. The OFB operation is identical for encryption or decryption, therefore no operation mode needs to be specified. After the operation is complete, call function mbedtls_aes_free to clear the AES context.

15.1.4 Cryptographic Algorithms – DES

The DES algorithm sample application demonstrates common use cases of DES and Triple-DES ciphers. The sample application runs two types of cryptography algorithms:

- DES-CBC-56
- DES3-CBC-112 and 168

```
>>> Start STA mode...
* DES -CBC- 56 (dec): passed
* DES -CBC- 56 (enc): passed
* DES3-CBC-112 (dec): passed
* DES3-CBC-112 (enc): passed
* DES3-CBC-168 (dec): passed
* DES3-CBC-168 (enc): passed
```

Figure 97: Result of Crypto DES

15.1.4.1 Application Initialization

The example below shows how a user uses DES algorithms of the “mbedTLS” library to encrypt and decrypt data.

```
void crypto_sample_des(void *param)
{
#if defined(MBEDTLS_CIPHER_MODE_CBC)
    crypto_sample_des_cbc();
#endif // (MBEDTLS_CIPHER_MODE_CBC)
    return ;
}
```

15.1.4.2 DES-CBC-56, DES3-CBC-112, and 168

DA16200 supports cryptographic algorithms for DES-CBC-56, DES3-CBC-112, and 168.

```
int crypto_sample_des_cbc()
{
    mbedtls_des_context *ctx = NULL;
    mbedtls_des3_context *ctx3 = NULL;

    // Initialize the DES context.
    mbedtls_des_init(ctx);
```

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```
    // Initialize the Triple-DES context.
    mbedtls_des3_init(ctx3);

    // Test CBC
    for (i = 0; i < 6; i++) {
        u = i >> 1;
        v = i  & 1;

        PRINTF("* DES%c-CBC-%3d (%s): ",
                ( u == 0 ) ? ' ' : '3', 56 + u * 56,
                ( v == MBEDTLS_DES_DECRYPT ) ? "dec" : "enc" );


        switch (i) {
            case 0: {
                // DES key schedule (56-bit, decryption).
                mbedtls_des_setkey_dec(ctx, crypto_sample_des3_keys);
            }
            break;
            case 1: {
                // DES key schedule (56-bit, encryption).
                mbedtls_des_setkey_enc(ctx, crypto_sample_des3_keys);
            }
            break;
            case 2: {
                // Triple-DES key schedule (112-bit, decryption).
                mbedtls_des3_set2key_dec(ctx3, crypto_sample_des3_keys);
            }
            break;
            case 3: {
                // Triple-DES key schedule (112-bit, encryption).
                mbedtls_des3_set2key_enc(ctx3, crypto_sample_des3_keys);
            }
            break;
            case 4: {
                // Triple-DES key schedule (168-bit, decryption).
                mbedtls_des3_set3key_dec(ctx3, crypto_sample_des3_keys);
            }
            break;
            case 5: {
                // Triple-DES key schedule (168-bit, encryption).
                mbedtls_des3_set3key_enc(ctx3, crypto_sample_des3_keys);
            }
            break;
        }

        if (v == MBEDTLS_DES_DECRYPT) {
            for (j = 0 ; j < CRYPTO_SAMPLE_DES_LOOP_COUNT ; j++) {
                if (u == 0) {
                    // DES-CBC buffer decryption.
                    mbedtls_des_crypt_cbc(ctx, v, 8, iv, buf, buf);
                } else {
                    // 3DES-CBC buffer decryption.
                    mbedtls_des3_crypt_cbc(ctx3, v, 8, iv, buf, buf);
                }
            }
        } else {
            for (j = 0; j < CRYPTO_SAMPLE_DES_LOOP_COUNT; j++) {
                if (u == 0) {
```

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```
                    // DES-CBC buffer encryption.
                    mbedtls_des_crypt_cbc(ctx, v, 8, iv, buf, buf);
                } else {
                    // 3DES-CBC buffer encryption.
                    mbedtls_des3_crypt_cbc(ctx3, v, 8, iv, buf, buf);
                }
            }
        }
    }

    // Clear the DES context.
    mbedtls_des_free(ctx);

    // Clear the Triple-DES context.
    mbedtls_des3_free(ctx3);
}
```

The mbedtls_des_context is the DES context structure. It is initialized by function mbedtls_des_init. Function mbedtls_des_crypt_cbc does DES-CBC buffer encryption and decryption. Before that, the key should be set up by function mbedtls_des_setkey_enc. After the operation is complete, call function mbed_des_free to clear the DES context.

The mbedtls_des3_context is the Triple-DES context structure. It is initialized by function mbedtls_des3_init. There are two key-sizes supported: 112 bits and 168 bits. Based on the key-size, the key is set up via function mbedtls_des3_set2key_enc (or mbedtls_des3_set2key_dec) or mbedtls_des3_set3key_enc(or mbedtls_des3_set3key_dec). After that, the function mbedtls_des3_crypt_cbc does Triple-DES CBC encryption and decryption. After the operation is complete, call function mbedtls_des3_free to clear the DES3 context.

15.1.5 Cryptographic Algorithms – HASH and HMAC

The HASH and HMAC algorithms sample application demonstrates common use cases of HASH and HMAC algorithms such as SHA-1, SHA-256, and SHA-512. The sample application runs six types of hash algorithms and HMAC algorithms:

- SHA1, SHA-224, SHA-256, SHA-384, SHA-512, and MD5
- HMAC

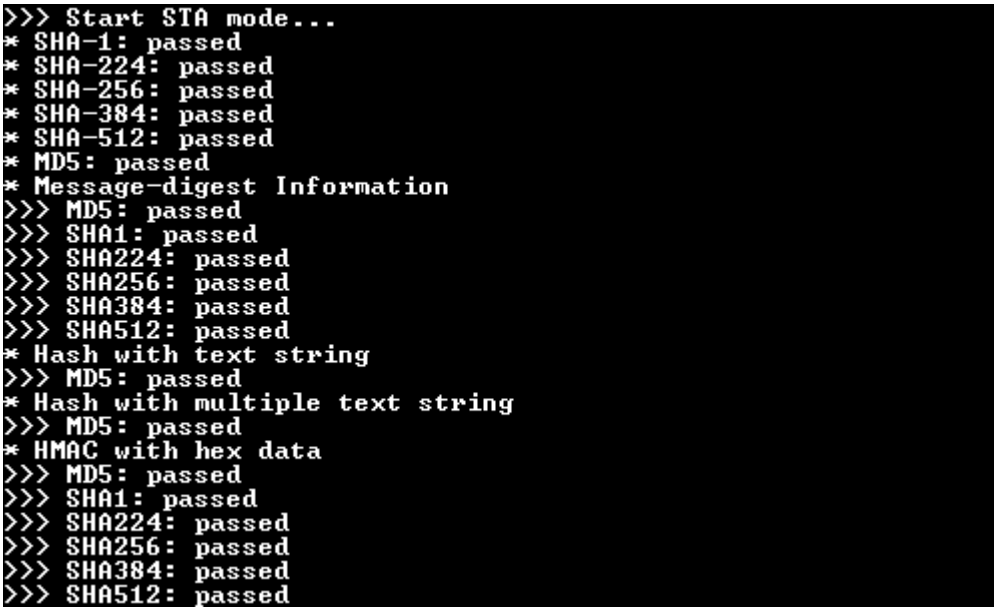

Figure 98: Result of Crypto HASH #1

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```
* HMAC with multiple hex data
>>> MD5: passed
>>> SHA1: passed
>>> SHA224: passed
>>> SHA256: passed
>>> SHA384: passed
>>> SHA512: passed
* Hash with hex data
>>> SHA1: passed
>>> SHA224: passed
>>> SHA256: passed
>>> SHA384: passed
>>> SHA512: passed
* Hash with multiple hex data
>>> SHA1: passed
>>> SHA224: passed
>>> SHA256: passed
>>> SHA384: passed
>>> SHA512: passed
```

Figure 99: Result of Crypto HASH #2

15.1.5.1 Application Initialization

This example describes how the user can use hash and HMAC algorithms of the “mbedTLS” library.

```
void crypto_sample_hash(void *param)
{
      crypto_sample_hash_sha1();

      crypto_sample_hash_sha224();

      crypto_sample_hash_sha256();

      crypto_sample_hash_sha384();

      crypto_sample_hash_sha512();

#if defined(MBEDTLS_MD5_C)
      crypto_sample_hash_md5();
#endif // (MBEDTLS_MD5_C)

      crypto_sample_hash_md_wrapper();

      return ;
}
```

15.1.5.2 SHA-1 Hash

DA16200 supports cryptographic algorithms for the SHA-1 hash. To explain how the SHA-1 hash works, see the test vector in FIPS-180-1.

```
int crypto_sample_hash_sha1()
{
    mbedtls_sha1_context *ctx = NULL;

    PRINTF("* SHA-1: ");

    // Initialize a SHA-1 context.
    mbedtls_sha1_init(ctx);

    // Start a SHA-1 checksum calculation.
    mbedtls_sha1_starts_ret(ctx);

    // Feed an input buffer into an ongoing SHA-1 checksum calculation.
    mbedtls_sha1_update_ret(ctx, crypto_sample_hash_sha1_buf,
```

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```
                                crypto_sample_hash_sha1_buflen);

    // Finish the SHA-1 operation, and writes the result to the output buffer.
    mbedtls_sha1_finish(ctx, sha1sum);

    // Clear a SHA-1 context.
    mbedtls_sha1_free(ctx);
}
```

The mbedtls_sha1_context is the SHA-1 context structure. Function mbedtls_sha1_init is called to initialize the context. To calculate SHA-1 Hash, three functions should be called. The details are below.

Table 36: APIs for SHA-1 Hach

Item	Description
int mbedtls_sha1_starts_ret(mbedtls_sha1_context *ctx)	
Prototype	int mbedtls_sha1_starts_ret(mbedtls_sha1_context *ctx)
Parameter	ctx: The SHA-1 context to initialize. This must be initialized.
Return	0 on success. A negative error code on failure.
Description	This function starts a SHA-1 checksum calculation.
int mbedtls_sha1_update_ret(mbedtls_sha1_context *ctx, const unsigned char *input, size_t ilen)	
Prototype	int mbedtls_sha1_update_ret(mbedtls_sha1_context *ctx, const unsigned char *input, size_t ilen)
Parameter	ctx: The SHA-1 context. This must be initialized and have a hash operation started. input: The buffer holding the input data. This must be a readable buffer of length ilen Bytes. ilen: The length of the input data input in Bytes.
Return	0 on success. A negative error code on failure.
Description	This function feeds an input buffer into an ongoing SHA-1 checksum calculation.
int mbedtls_sha1_finish_ret(mbedtls_sha1_context *ctx, unsigned char output[20])	
Prototype	int mbedtls_sha1_finish_ret(mbedtls_sha1_context *ctx, unsigned char output[20])
Parameter	ctx: The SHA-1 context to use. This must be initialized and have a hash operation started. output: The SHA-1 checksum result. This must be a writable buffer of length 20 Bytes.
Return	0 on success. A negative error code on failure.
Description	This function finishes the SHA-1 operation and writes the result to the output buffer.

15.1.5.3 SHA-224 Hash

DA16200 supports cryptographic algorithms for the SHA-224 hash. To explain how SHA-224 hash works, see the test vector in FIPS-180-2.

```
int crypto_sample_hash_sha224()
{
      mbedtls_sha256_context *ctx = NULL;

      PRINTF("* SHA-224: ");

      // Initialize the SHA-224 context.
      mbedtls_sha256_init(ctx);
```

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```
    // Start a SHA-224 checksum calculation.
    mbedtls_sha256_starts_ret(ctx, 1);

    // Feeds an input buffer into an ongoing SHA-224 checksum calculation.
    mbedtls_sha256_update_ret(ctx, crypto_sample_hash_sha224_buf,
                              crypto_sample_hash_sha224_buflen);

    // Finishes the SHA-224 operation, and writes the result to the output buffer.
    mbedtls_sha256_finish_ret(ctx, sha224sum);

    //Clear s SHA-224 context.
    mbedtls_sha256_free(ctx);
}
```

The mbedtls_sha256_context is the SHA-256 context structure. The “mbedTLS” library supports SHA-224 and SHA-256 using the context. This sample describes SHA-224. Call function mbedtls_sha256_init to initialize the context. To calculate SHA-224 Hash, three functions should be called. The details are below.

Table 37: APIs for SHA-224 and SHA-256 Hash

Item	Description
int mbedtls_sha256_starts_ret(mbedtls_sha256_context *ctx, int is224)	
Prototype	int mbedtls_sha256_starts_ret(mbedtls_sha256_context *ctx, int is224)
Parameter	ctx: The context to use. This must be initialized. is224: This determines which function to use. This must be either 0 for SHA-256, or 1 for SHA-224.
Return	0 on success. A negative error code on failure.
Description	This function starts a SHA-224 or SHA-256 checksum calculation.
int mbedtls_sha256_update_ret(mbedtls_sha256_context *ctx, const unsigned char *input, size_t ilen)	
Prototype	int mbedtls_sha256_update_ret(mbedtls_sha256_context *ctx, const unsigned char *input, size_t ilen)
Parameter	ctx: The SHA-256 context. This must be initialized and have a hash operation started. input: The buffer holding the input data. This must be a readable buffer of length ilen Bytes. ilen: The length of the input data input in Bytes.
Return	0 on success. A negative error code on failure.
Description	This function feeds an input buffer into an ongoing SHA-256 checksum calculation.
int mbedtls_sha256_finish_ret(mbedtls_sha256_context *ctx, unsigned char output[32])	
Prototype	int mbedtls_sha256_finish_ret(mbedtls_sha256_context *ctx, unsigned char output[32])
Parameter	ctx: The SHA-256 context to use. This must be initialized and have a hash operation started. output: The SHA-224 or SHA-256 checksum result. This must be a writable buffer of length 32 Bytes.
Return	0 on success. A negative error code on failure.
Description	This function finishes the SHA-256 operation and writes the result to the output buffer.

15.1.5.4 SHA-256 Hash

DA16200 supports cryptographic algorithms for the SHA-256 hash. To explain how the SHA-256 hash works, see the test vector in FIPS-180-2.

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```
int crypto_sample_hash_sha256()
{
    mbedtls_sha256_context *ctx = NULL;

    PRINTF("* SHA-256: ");

    // Initialize the SHA-256 context.
    mbedtls_sha256_init(ctx);

    // Start a SHA-256 checksum calculation.
    mbedtls_sha256_starts_ret(ctx, 0);

    // Feeds an input buffer into an ongoing SHA-256 checksum calculation.
    mbedtls_sha256_update_ret(ctx, rypto_sample_hash_sha256_buf,
                              crypto_sample_hash_sha256_buflen);

    // Finishe the SHA-256 operation, and writes the result to the output buffer.
    mbedtls_sha256_finish_ret(ctx, sha256sum);

    //Clear s SHA-256 context.
    mbedtls_sha256_free(ctx);
}
```

This example is the same as the Cryptographic Algorithm for the SHA-224 code (see Section 15.1.5.3). When starting the SHA-256 checksum calculation, the second parameter should be set to 0 for SHA-256.

15.1.5.5 SHA-384 Hash

DA16200 supports cryptographic algorithms for the SHA-384 hash. To explain how the SHA-384 hash works, see the test vector in FIPS-180-2.

```
int crypto_sample_hash_sha384()
{
    mbedtls_sha512_context *ctx = NULL;

    PRINTF("* SHA-384: ");

    // Initialize a SHA-384 context.
    mbedtls_sha512_init(ctx);

    // Start a SHA-384 checksum calculation.
    mbedtls_sha512_starts_ret(ctx, 1);

    // Feed an input buffer into an ongoing SHA-384 checksum calculation.
    mbedtls_sha512_update(ctx, crypto_sample_hash_sha384_buf,
                          crypto_sample_hash_sha384_buflen);

    // Finishe the SHA-384 operation, and writes the result to the output buffer.
    mbedtls_sha512_finish(ctx, sha384sum);

    // Clear a SHA-384 context.
    mbedtls_sha512_free(ctx);
}
```

The mbedtls_sha512_context is the SHA-512 context structure. “mbedTLS” library supports SHA-384 and SHA-512 using the context. This example describes SHA-384. Function mbedtls_sha512_init is called to initialize the context. To calculate SHA-384 Hash, three functions should be called. The details are below.

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Table 38: APIs for SHA-384 and SHA-512 HASH

Item	Description
int mbedtls_sha512_starts_ret(mbedtls_sha512_context *ctx, int is384)	
Prototype	int mbedtls_sha512_starts_ret(mbedtls_sha512_context *ctx, int is384)
Parameter	ctx: The context to use. This must be initialized. is384: This determines which function to use. This must be either 0 for SHA-512, or 1 for SHA-384.
Return	0 on success. A negative error code on failure.
Description	This function starts a SHA-384 or SHA-512 checksum calculation.
int mbedtls_sha512_update_ret(mbedtls_sha512_context *ctx, const unsigned char *input, size_t ilen)	
Prototype	int mbedtls_sha512_update_ret(mbedtls_sha512_context *ctx, const unsigned char *input, size_t ilen)
Parameter	ctx: The SHA-512 context. This must be initialized and have a hash operation started. input: The buffer holding the input data. This must be a readable buffer of length ilen Bytes. ilen: The length of the input data input in Bytes.
Return	0 on success. A negative error code on failure.
Description	This function feeds an input buffer into an ongoing SHA-512 checksum calculation.
int mbedtls_sha512_finish_ret(mbedtls_sha512_context *ctx, unsigned char output[64])	
Prototype	int mbedtls_sha512_finish_ret(mbedtls_sha512_context *ctx, unsigned char output[64])
Parameter	ctx: The SHA-512 context to use. This must be initialized and start a hash operation. output: The SHA-384 or SHA-512 checksum result. This must be a writable buffer of length 64 Bytes.
Return	0 on success. A negative error code on failure.
Description	This function finishes the SHA-512 operation and writes the result to the output buffer.

15.1.5.6 SHA-512 Hash

DA16200 supports cryptographic algorithms for the SHA-512 hash. To explain how the SHA-512 hash works, see the test vector in FIPS-180-2.

```
int crypto_sample_hash_sha512()
{
    mbedtls_sha512_context *ctx = NULL;

    PRINTF("* SHA-512: ");

    // Initialize a SHA-512 context.
    mbedtls_sha512_init(ctx);

    // Start a SHA-512 checksum calculation.
    mbedtls_sha512_starts_ret(ctx, 0);

    // Feed an input buffer into an ongoing SHA-512 checksum calculation.
    mbedtls_sha512_update_ret(ctx, crypto_sample_hash_sha512_buf,
                              crypto_sample_hash_sha512_buflen);

    // Finishe the SHA-512 operation, and writes the result to the output buffer.
    mbedtls_sha512_finish(ctx, sha512sum);
```

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```
    // Clear a SHA-512 context.
    mbedtls_sha512_free(ctx);
}
```

This sample is the same as Cryptographic Algorithm for the SHA-384 code (see Section 15.1.5.5). When the SHA-512 checksum calculation is started, the second parameter should be set to 0 for SHA-512.

15.1.5.7 MD5 Hash

DA16200 supports cryptographic algorithms for an MD5 hash. To explain how the MD5 hash works, see the test vector in RFC1321.

```
int crypto_sample_hash_md5()
{
    PRINTF("* MD5: ");

    // Output = MD5(input buffer)
    mbedtls_md5_ret(crypto_sample_hash_md5_buf,
                    crypto_sample_hash_md5_buflen, md5sum);
    return ret;
}
```

In this example, the MD5 hash function is calculated by function mbedtls_md5_ret. The details are as follows:

Table 39: APIs for MD5 Hash

Item	Description
int mbedtls_md5_ret(const unsigned char *input, size_t ilen, unsigned char output[16])	
Prototype	int mbedtls_md5_ret(const unsigned char *input, size_t ilen, unsigned char output[16])
Parameter	Input: buffer holding the data Ilen: length of the input data Output: MD5 checksum result
Return	0 if successful
Description	Output = MD5 (input buffer)

15.1.5.8 HASH and HMAC with Generic Message-Digest Wrapper

The **mbedTLS** library provides the generic message-digest wrapper to calculate HASH and HMAC. The APIs and sample codes below show how HASH and HMAC are calculated with the generic message-digest wrapper functions. The API details are as follows:

Table 40: APIs for Generic Message Digest Wrapper

Item	Description
const mbedtls_md_info_t* mbedtls_md_info_from_type(mbedtls_md_type_t md_type)	
Prototype	const mbedtls_md_info_t* mbedtls_md_info_from_type(mbedtls_md_type_t md_type) c
Parameter	md_type: The type of digest to search for.
Return	The message-digest information associated with md_type. NULL if the associated message-digest information is not found.

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Item	Description
Description	This function returns the message-digest information associated with the given digest type.
const mbedtls_md_info_t* mbedtls_md_info_from_string(const char* md_name)	
Prototype	const mbedtls_md_info_t* mbedtls_md_info_from_string(const char* md_name) (Note 1)
Parameter	md_name: The name of the digest to search for.
Return	The message-digest information associated with md_name. NULL if the associated message-digest information is not found.
Description	This function returns the message-digest information associated with the given digest name.
mbedtls_md_type_t mbedtls_md_get_type(const mbedtls_md_info_t* md_info)	
Prototype	const mbedtls_md_info_t* mbedtls_md_info_from_string(const char* md_name) (Note 1)
Parameter	md_info: The information structure of the message-digest algorithm to use.
Return	The type of the message digest.
Description	This function extracts the message-digest type from the message-digest information structure.
unsigned char mbedtls_md_get_size(const mbedtls_md_info_t* md_info)	
Prototype	unsigned char mbedtls_md_get_size(const mbedtls_md_info_t* md_info) (Note 1)
Parameter	md_info: The information structure of the message-digest algorithm to use.
Return	The size of the message-digest output in Bytes.
Description	This function extracts the message-digest size from the message-digest information structure.
const char* mbedtls_md_get_name(const mbedtls_md_info_t* md_info)	
Prototype	const char* mbedtls_md_get_name(const mbedtls_md_info_t* md_info) (Note 1)
Parameter	md_info: The information structure of the message-digest algorithm to use.
Return	The name of the message digest.
Description	This function extracts the message-digest name from the message-digest information structure.
const int* mbedtls_md_list(void)	
Prototype	const int* mbedtls_md_list(void) (Note 1)
Parameter	None.
Return	A statically allocated array of digests. Each element in the returned list is an integer belonging to the message-digest enumeration mbedtls_md_type_t. The last entry is 0.
Description	This function returns the list of digests supported by the generic digest module.
int mbedtls_md(const mbedtls_md_info_t* md_info, const unsigned char* input, size_t ilen, unsigned char* output)	
Prototype	int mbedtls_md(const mbedtls_md_info_t* md_info, const unsigned char* input, size_t ilen, unsigned char* output) (Note 2)
Parameter	md_info: The information structure of the message-digest algorithm to use. input: The buffer holding the data. ilen: The length of the input data. output: The generic message-digest checksum result.

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Item	Description
Return	0 on success. MBEDTLS_ERR_MD_BAD_INPUT_DATA on parameter-verification failure.
Description	This function calculates the message-digest of a buffer, with respect to a configurable message-digest algorithm in a single call. The result is calculated as Output = message_digest(input buffer).
void mbedtls_md_init(mbedtls_md_context_t* ctx)	
Prototype	void mbedtls_md_init(mbedtls_md_context_t* ctx) (Note 3)
Parameter	ctx: The context to initialize.
Return	None
Description	This function initializes a message-digest context without binding to a particular message-digest algorithm.
int mbedtls_md_setup(mbedtls_md_context_t* ctx, const mbedtls_md_info_t * md_info, int hmac)	
Prototype	int mbedtls_md_setup(mbedtls_md_context_t* ctx, const mbedtls_md_info_t * md_info, int hmac) (Note 3)
Parameter	ctx: The context to set up. md_info: The information structure of the message-digest algorithm to use. hmac: Defines if HMAC is used. 0: HMAC is not used (saves some memory), or non-zero: HMAC is used with this context.
Return	0 on success. MBEDTLS_ERR_MD_BAD_INPUT_DATA on parameter-verification failure. MBEDTLS_ERR_MD_ALLOC_FAILED on memory-allocation failure.
Description	This function selects the message digest algorithm to use and allocates internal structures.
int mbedtls_md_update(mbedtls_md_context_t* ctx, const unsigned char* input, size_t ilen)	
Prototype	int mbedtls_md_update(mbedtls_md_context_t* ctx, const unsigned char* input, size_t ilen) (Note 3)
Parameter	ctx: The generic message-digest context. input: The buffer holding the input data. ilen: The length of the input data.
Return	0 on success. MBEDTLS_ERR_MD_BAD_INPUT_DATA on parameter-verification failure.
Description	This function feeds an input buffer into an ongoing message-digest computation.
int mbedtls_md_finish(mbedtls_md_context_t* ctx, unsigned char* output)	
Prototype	int mbedtls_md_finish(mbedtls_md_context_t* ctx, unsigned char* output) (Note 3)
Parameter	ctx: The generic message-digest context. output: The buffer for the generic message-digest checksum result.
Return	0 on success. MBEDTLS_ERR_MD_BAD_INPUT_DATA on parameter-verification failure.
Description	This function finishes the digest operation and writes the result to the output buffer.
void mbedtls_md_free(mbedtls_md_context_t* ctx)	
Prototype	void mbedtls_md_free(mbedtls_md_context_t* ctx) (Note 3)
Parameter	ctx: The generic message-digest context.
Return	None.
Description	This function clears the internal structure of ctx and frees any embedded internal structure but does not free ctx itself.

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Item	Description
int mbedtls_md_hmac(const mbedtls_md_info_t* md_info, const unsigned char* key, size_t keylen, const unsigned char* input, size_t ilen, unsigned char* output)	
Prototype	int mbedtls_md_hmac(const mbedtls_md_info_t* md_info, const unsigned char* key, size_t keylen, const unsigned char* input, size_t ilen, unsigned char* output) (Note 4)
Parameter	md_info: The information structure of the message-digest algorithm to use. key: The HMAC secret key. keylen: The length of the HMAC secret key in Bytes. input: The buffer holding the input data. ilen: The length of the input data. output: The generic HMAC result.
Return	0 on success. MBEDTLS_ERR_MD_BAD_INPUT_DATA on parameter-verification failure.
Description	This function calculates the full generic HMAC on the input buffer with the provided key. The function allocates the context, does the calculation, and frees the context. The HMAC result is calculated as output = generic HMAC (hmac key, input buffer).
int mbedtls_md_hmac_starts(mbedtls_md_context_t* ctx, const unsigned char* key, size_t keylen)	
Prototype	int mbedtls_md_hmac_starts(mbedtls_md_context_t* ctx, const unsigned char* key, size_t keylen) (Note 4)
Parameter	ctx: The message digest context containing an embedded HMAC context. key: The HMAC secret key. keylen: The length of the HMAC key in Bytes.
Return	0 on success. MBEDTLS_ERR_MD_BAD_INPUT_DATA on parameter-verification failure.
Description	This function sets the HMAC key and prepares to authenticate a new message.
int mbedtls_md_hmac_update(mbedtls_md_context_t* ctx, const unsigned char* input, size_t ilen)	
Prototype	int mbedtls_md_hmac_update(mbedtls_md_context_t* ctx, const unsigned char* input, size_t ilen) (Note 4)
Parameter	ctx: The message digest context containing an embedded HMAC context. input: The buffer holding the input data. ilen: The length of the input data.
Return	0 on success. MBEDTLS_ERR_MD_BAD_INPUT_DATA on parameter-verification failure.
Description	This function feeds an input buffer into an ongoing HMAC computation.
int mbedtls_md_hmac_finish(mbedtls_md_context_t* ctx, unsigned char* output)	
Prototype	int mbedtls_md_hmac_finish(mbedtls_md_context_t* ctx, unsigned char* output) (Note 4)
Parameter	ctx: The message digest context containing an embedded HMAC context. output: The generic HMAC checksum result.
Return	0 on success. MBEDTLS_ERR_MD_BAD_INPUT_DATA on parameter-verification failure.
Description	This function finishes the HMAC operation and writes the result to the output buffer.

Note 1 Supported message-digest functions

The user needs to check which message-digests are supported by the "mbedTLS" library. The sample code below shows how to get and check message-digest information.

```
int crypto_sample_hash_md_wrapper_info(char *md_name, mbedtls_md_type_t md_type, int
md_size)
```

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```
{
    const mbedtls_md_info_t *md_info = NULL;
    const int *md_type_ptr = NULL;

    // Get the message-digest information associated with the given digest type.
    md_info = mbedtls_md_info_from_type(md_type);
    if (!md_info) {
        PRINTF("[%s] Unknown Hash Type(%d)\r\n", __func__, md_type);
        goto cleanup;
    }

    // Get the message-digest information associated with the given digest name.
    if (md_info != mbedtls_md_info_from_string(md_name)) {
        PRINTF("[%s] Unknown Hash Name(%s)\r\n", md_name);
        goto cleanup;
    }

    // Extract the message-digest type from the message-digest information
    // structure.
    if (mbedtls_md_get_type(md_info) != (mbedtls_md_type_t)md_type) {
        PRINTF("[%s] Not matched Hash Type\r\n", __func__);
        goto cleanup;
    }

    // Extract the message-digest size from the message-digest information
    // structure.
    if (mbedtls_md_get_size(md_info) != (unsigned char)md_size) {
        PRINTF("[%s] Not matched Hash Size\r\n", __func__);
        goto cleanup;
    }

    // Extract the message-digest name from the message-digest information
    // structure.
    if (strcmp(mbedtls_md_get_name(md_info), md_name) != 0) {
        PRINTF("[%s] Not matched Hash Name\r\n", __func__);
        goto cleanup;
    }

    // Find the list of digests supported by the generic digest module.
    for (md_type_ptr = mbedtls_md_list() ; *md_type_ptr != 0 ; md_type_ptr++) {
        if (*md_type_ptr == md_type) {
            found = 1;
            break;
        }
    }

    return ret;
}
```

Note 2 How to calculate HASH using a single text string

The sample code below describes how a HASH function is calculated using the generic message-digest. In this sample, the text_src_string is used to calculate the message-digest algorithm, and the expected output is hex_hash_string.

```
int crypto_sample_hash_md_wrapper_text(char *md_name, char *text_src_string, char
*hex_hash_string)
{
    const mbedtls_md_info_t *md_info = NULL;

    // Get the message-digest information associated with the given digest name.
    md_info = mbedtls_md_info_from_string(md_name);
```

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```
    /* Calculates the message-digest of a buffer,
     * with respect to a configurable message-digest algorithm in a single call.
     */
    ret = mbedtls_md(md_info,
                     (const unsigned char *)text_src_string,
                      strlen(text_src_string),
                      output);
}
```

Note 3 How to calculate HASH using multiple text strings

The sample code is similar to the Note 2 and the only difference is that multiple text strings are used.

```
int crypto_sample_hash_md_wrapper_text_multi(char *md_name, char *text_src_string,
char *hex_hash_string)
{
    const mbedtls_md_info_t *md_info = NULL;
    mbedtls_md_context_t *ctx = NULL;       //The generic message-digest context.

    /* Initialize a message-digest context without binding it
     * to a particular message-digest algorithm.
     */
    mbedtls_md_init(ctx);

    // Get the message-digest information associated with the given digest name.
    md_info = mbedtls_md_info_from_string(md_name);

    // Select the message digest algorithm to use, and allocates internal
    // structures.
    ret = mbedtls_md_setup(ctx, md_info, 0);

    // Start a message-digest computation.
    ret = mbedtls_md_starts(ctx);

    // Feed an input buffer into an ongoing message-digest computation.
    ret = mbedtls_md_update(ctx, (const unsigned char *)text_src_string, halfway);

    // Feed an input buffer into an ongoing message-digest computation.
    ret = mbedtls_md_update(ctx,
                            (const unsigned char *)(text_src_string + halfway),
                            len - halfway);
    // Finish the digest operation, and writes the result to the output buffer.
    ret = mbedtls_md_finish(ctx, output);

    /* Clear the internal structure of ctx and free any embedded internal
       structure,
     * but does not free ctx itself.
     */
    mbedtls_md_free(ctx);
}
```

Note 4 How to calculate HMAC using a single hex data

The sample code below shows how the HMAC function is calculated using the generic message-digest wrapper. The hex_key_string is the HMAC secret key, the hex_src_string is input data, and the hex_hash_string is expected output. The mbedtls_md_hmac is for a single hex data.

```
int crypto_sample_hash_md_wrapper_hmac(char *md_name, int trunc_size, char
*hex_key_string, char *hex_src_string, char *hex_hash_string)
{
    const mbedtls_md_info_t *md_info = NULL;

    // Get the message-digest information associated with the given digest name.
```

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```
    md_info = mbedtls_md_info_from_string(md_name);

    // Calculate the full generic HMAC on the input buffer with the provided key.
    ret = mbedtls_md_hmac(md_info, key_str, key_len, src_str, src_len, output);
}
```

Note 5 How to calculate HMAC using multiple hex data

The sample code is similar to the Note 4 and the only difference is that multiple hex data are used for input value.

```
int crypto_sample_hash_md_wrapper_hmac_multi(char *md_name, int trunc_size, char
*hex_key_string, char *hex_src_string, char *hex_hash_string)
{
    const mbedtls_md_info_t *md_info = NULL;
    mbedtls_md_context_t *ctx = NULL;

    /* Initialize a message-digest context without binding it
     * to a particular message-digest algorithm.
     */
    mbedtls_md_init(ctx);

    md_info = mbedtls_md_info_from_string(md_name);

    // Select the message digest algorithm to use, and allocate internal
    // structures.
    ret = mbedtls_md_setup(ctx, md_info, 1);

    // Start a message-digest computation.
    ret = mbedtls_md_hmac_starts(ctx, key_str, key_len);

    // Feed an input buffer into an ongoing message-digest computation.
    ret = mbedtls_md_hmac_update(ctx, src_str, halfway);

    // Feed an input buffer into an ongoing message-digest computation.
    ret = mbedtls_md_hmac_update(ctx, src_str + halfway, src_len - halfway);

    // Finish the digest operation, and writes the result to the output buffer.
    ret = mbedtls_md_hmac_finish(ctx, output);

    /* Clear the internal structure of ctx and free any embedded internal
       structure,
     * but does not free ctx itself.
     */
    mbedtls_md_free(ctx);
}
```

Note 6 How to calculate HASH using a single hex data

The sample code below describes how the HASH function is calculated with the generic message-digest function. The code is similar to the Note 2 and the only difference is that a single hex data is used for input value.

```
int crypto_sample_hash_md_wrapper_hex(char *md_name, char *hex_src_string, char
*hex_hash_string)
{
    const mbedtls_md_info_t *md_info = NULL;

    // Get the message-digest information associated with the given digest name.
    md_info = mbedtls_md_info_from_string(md_name);

    /* Calculates the message-digest of a buffer,
     * with respect to a configurable message-digest algorithm in a single call.
     */
```

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```
    ret = mbedtls_md(md_info, src_str, src_len, output);
}
```

Note 7 How to calculate HASH using multiple hex data

The sample code below describes how the HASH function is calculated with the generic message-digest function. The code is similar to the Note 3 and the only difference is that multiple hex data are used for input value.

```
int crypto_sample_hash_md_wrapper_hex_multi(char *md_name, char *hex_src_string,
char *hex_hash_string)
{
    const mbedtls_md_info_t *md_info = NULL;
    mbedtls_md_context_t *ctx = NULL;

    /* Initialize a message-digest context without binding it
     * to a particular message-digest algorithm.
     */
    mbedtls_md_init(ctx);

    // Get the message-digest information associated with the given digest name.
    md_info = mbedtls_md_info_from_string(md_name);

    // Select the message digest algorithm to use, and allocate internal
    // structures.
    ret = mbedtls_md_setup(ctx, md_info, 0);

    // Start a message-digest computation.
    ret = mbedtls_md_starts(ctx);

    // Feed an input buffer into an ongoing message-digest computation.
    ret = mbedtls_md_update(ctx, src_str, halfway);

    // Feed an input buffer into an ongoing message-digest computation.
    ret = mbedtls_md_update(ctx, src_str + halfway, src_len - halfway);

    // Finish the digest operation, and writes the result to the output buffer.
    ret = mbedtls_md_finish(ctx, output);

    /* Clear the internal structure of ctx and free any embedded internal
       structure,
     * but does not free ctx itself.
     */

    mbedtls_md_free(ctx);
}
```

15.1.6 Cryptographic Algorithms – DRBG

The Random generator sample application demonstrates common use cases of CTR-DRBG (Counter mode Deterministic Random Byte Generator) and HMAC-DRBG (HMAC Deterministic Random Byte Generator). The sample application explains how to use the DRBG function with CTR and HMAC.

- CTR_DRBG
- HMAC_DRBG

```
* CTR_DRBG (PR = TRUE): passed
* CTR_DRBG (PR = FALSE): passed
* HMAC_DRBG (PR = True) : passed
* HMAC_DRBG (PR = False) : passed
```

Figure 100: Result of Crypto DRBG

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15.1.6.1 Application Initialization

This example describes how the user uses CTR DRBG and HMAC DRBG of the "mbedTLS" library. CTR_DRBG is a standardized way of building a PRNG from a block-cipher in counter mode operation, as defined in NIST SP 800-90A: Recommendation for Random Number Generation Using Deterministic Random Bit Generators. To implement "mbedTLS" of CTR_DRBG, use AES-256 (default) or AES-128 as the underlying block cipher. HMAC_DRBG is based on a Hash-based message authentication code.

```
void crypto_sample_drbg(void *param)
{
    crypto_sample_ctr_drbg_pr_on();

    crypto_sample_ctr_drbg_pr_off();

    crypto_sample_hmac_drbg_pr_on();

    crypto_sample_hmac_drbg_pr_off();

    return ;
}
```

15.1.6.2 CTR_DRBG with Prediction Resistance

This example describes how to use CTR_DRBG with prediction resistance.

```
int crypto_sample_ctr_drbg_pr_on()
{
    mbedtls_ctr_drbg_context *ctx = NULL;   //The CTR_DRBG context structure.

    // Based on a NIST CTR_DRBG test vector (PR = True)
    PRINTF("* CTR_DRBG (PR = TRUE): ");

    // Initialize the CTR_DRBG context.
    mbedtls_ctr_drbg_init( ctx );

    ret = mbedtls_ctr_drbg_seed_entropy_len(ctx, drbg_test_entropy,
                                    (void *)crypto_sample_ctr_drbg_entropy_src_pr,
                                     crypto_sample_ctr_brdg_nonce_pers_pr,
                                     16,
                                     32);

    // Turn prediction resistance on
    mbedtls_ctr_drbg_set_prediction_resistance(ctx, MBEDTLS_CTR_DRBG_PR_ON);

    // Generate random data using CTR_DRBG.
    ret = mbedtls_ctr_drbg_random(ctx, buf, MBEDTLS_CTR_DRBG_BLOCKSIZE);

    // Generate random data using CTR_DRBG.
    ret = mbedtls_ctr_drbg_random(ctx, buf, MBEDTLS_CTR_DRBG_BLOCKSIZE);

    // Clear CTR_CRBG context data.
    mbedtls_ctr_drbg_free(ctx);
}
```

The API details are as follows:

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Table 41: APIs for CTR_DRBG

Item	Description
void mbedtls_ctr_drbg_init(mbedtls_ctr_drbg_context* ctx)	
Prototype	int mbedtls_md_hmac_starts(mbedtls_md_context_t* ctx, const unsigned char* key, size_t keylen)
Parameter	ctx: The CTR_DRBG context to initialize.
Return	None.
Description	This function initializes the CTR_DRBG context and prepares it for mbedtls_ctr_drbg_seed() or mbedtls_ctr_drbg_free().
void mbedtls_ctr_drbg_set_prediction_resistance(mbedtls_ctr_drbg_context* ctx, int resistance)	
Prototype	void mbedtls_ctr_drbg_set_prediction_resistance(mbedtls_ctr_drbg_ context* ctx, int resistance)
Parameter	resistance: MBEDTLS_CTR_DRBG_PR_ON or MBEDTLS_CTR_DRBG_PR_OFF.
Return	None.
Description	This function turns prediction resistance on or off. The default value is off.
int mbedtls_ctr_drbg_random(void* p_rng, unsigned char *output, size_t output_len)	
Prototype	int mbedtls_ctr_drbg_random(void* p_rng, unsigned char *output, size_t output_len)
Parameter	p_rng: The CTR_DRBG context. This must be a pointer to a mbedtls_ctr_drbg_context structure. output: The buffer to fill. output_len: The length of the buffer.
Return	0 on success. MBEDTLS_ERR_CTR_DRBG_ENTROPY_SOURCE_FAILED or MBEDTLS_ERR_CTR_DRBG_REQUEST_TOO_BIG on failure.
Description	This function uses CTR_DRBG to generate random data.
void mbedtls_ctr_drbg_free(mbedtls_ctr_drbg_context* ctx)	
Prototype	void mbedtls_ctr_drbg_free(mbedtls_ctr_drbg_context* ctx)
Parameter	ctx: The CTR_DRBG context to clear.
Return	None.
Description	This function clears CTR_CRBG context data.

15.1.6.3 CTR_DRBG Without Prediction Resistance

This example describes how to use CTR_DRBG without prediction resistance.

```
int crypto_sample_ctr_drbg_pr_off()
{
    mbedtls_ctr_drbg_context ctx;   //The CTR_DRBG context structure.

    // Based on a NIST CTR_DRBG test vector (PR = FALSE)
    PRINTF("* CTR_DRBG (PR = FALSE): ");

    // Initialize the CTR_DRBG context.
    mbedtls_ctr_drbg_init(&ctx);

    ret = mbedtls_ctr_drbg_seed_entropy_len(&ctx, drbg_test_entropy,
                                (void *) crypto_sample_ctr_drbg_entropy_src_nopr,
                                 crypto_sample_ctr_brdg_nonce_pers_nopr, 16, 32);
```

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```
    // Generate random data using CTR_DRBG.
    ret = mbedtls_ctr_drbg_random(&ctx, buf, MBEDTLS_CTR_DRBG_BLOCKSIZE);

    // Reseed the CTR_DRBG context, that is extracts data from the entropy source.
    ret = mbedtls_ctr_drbg_reseed(&ctx, NULL, 0);

    // Generate random data using CTR_DRBG.
    ret = mbedtls_ctr_drbg_random(&ctx, buf, MBEDTLS_CTR_DRBG_BLOCKSIZE);

    // Clear CTR_CRBG context data.
    mbedtls_ctr_drbg_free(&ctx);
}
```

15.1.6.4 HMAC_DRBG with Prediction Resistance

This example describes how to use HMAC_DRBG with prediction resistance.

```
int crypto_sample_hmac_drbg_pr_on()
{
     mbedtls_hmac_drbg_context ctx;
     const mbedtls_md_info_t *md_info = mbedtls_md_info_from_type(MBEDTLS_MD_SHA1);

     PRINTF("* HMAC_DRBG (PR = True) : ");

     // Initialize HMAC DRBG context.
     mbedtls_hmac_drbg_init(&ctx);

     // HMAC_DRBG initial seeding Seed and setup entropy source for future reseeds.
     ret = mbedtls_hmac_drbg_seed(&ctx, md_info,
                                  drbg_test_entropy,
                                  (void *)crypto_sample_hmac_drbg_entropy_src_pr,
                                  NULL, 0);

     // Enable prediction resistance.
     mbedtls_hmac_drbg_set_prediction_resistance(&ctx, MBEDTLS_HMAC_DRBG_PR_ON);

     // Generate random.
     ret = mbedtls_hmac_drbg_random(&ctx, buf, CRYPTO_SAMPLE_HMAC_DRBG_OUTPUT_LEN);

     // Generate random.
     ret = mbedtls_hmac_drbg_random(&ctx, buf, CRYPTO_SAMPLE_HMAC_DRBG_OUTPUT_LEN);

     // Free an HMAC_DRBG context.
     mbedtls_hmac_drbg_free(&ctx);
}
```

The API details are as follows:

Table 42: APIs for HMAC_DRBG

Item	Description
void mbedtls_hmac_drbg_init (mbedtls_hmac_drbg_context* ctx)	
Prototype	void mbedtls_hmac_drbg_init(mbedtls_hmac_drbg_context *ctx)
Parameter	ctx: HMAC_DRBG context to be initialized.
Return	None.
Description	HMAC_DRBG context initialization makes the context ready for mbedtls_hmac_drbg_seed(), mbedtls_hmac_drbg_seed_buf() or mbedtls_hmac_drbg_free().

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Item	Description
int mbedtls_hmac_drbg_seed(mbedtls_hmac_drbg_context* ctx, const mbedtls_md_info_t * md_info, int (*f_entropy)(void*, unsigned char*, size_t), void* p_entropy, const unsigned char* custom, size_t len)	
Prototype	int mbedtls_hmac_drbg_seed(mbedtls_hmac_drbg_context* ctx, const mbedtls_md_info_t * md_info, int (*f_entropy)(void*, unsigned char*, size_t), void* p_entropy, const unsigned char* custom, size_t len)
Parameter	ctx: HMAC_DRBG context to be seeded. md_info: MD algorithm to use for HMAC_DRBG. f_entropy: Entropy callback (p_entropy, buffer to fill, buffer length). p_entropy: Entropy context. custom: Personalization data (Device specific identifiers) (Can be NULL). len: Length of personalization data.
Return	0 if successful, or MBEDTLS_ERR_MD_BAD_INPUT_DATA, or MBEDTLS_ERR_MD_ALLOC_FAILED, or MBEDTLS_ERR_HMAC_DRBG_ENTROPY_SOURCE_FAILED.
Description	HMAC_DRBG initial seeding Seed and setup entropy source for future reseeds.
void mbedtls_hmac_drbg_set_prediction_resistance(mbedtls_hmac_drbg_context *ctx, int resistance)	
Prototype	void mbedtls_hmac_drbg_set_prediction_resistance(mbedtls_hmac_drbg_ context *ctx, int resistance)
Parameter	ctx: HMAC_DRBG context. resistance: MBEDTLS_HMAC_DRBG_PR_ON or MBEDTLS_HMAC_DRBG_PR_OFF.
Return	None.
Description	Enable / disable prediction resistance (Default: Off).
int mbedtls_hmac_drbg_random(void *p_rng, unsigned char *output, size_t out_len)	
Prototype	int mbedtls_hmac_drbg_random(void *p_rng, unsigned char *output, size_t out_len)
Parameter	p_rng: HMAC_DRBG context. output: Buffer to fill. out_len: Length of the buffer.
Return	0 if successful, or MBEDTLS_ERR_HMAC_DRBG_ENTROPY_SOURCE_FAILED, or MBEDTLS_ERR_HMAC_DRBG_REQUEST_TOO_BIG.
Description	HMAC_DRBG generate random.
void mbedtls_hmac_drbg_free(mbedtls_hmac_drbg_context *ctx)	
Prototype	void mbedtls_hmac_drbg_free(mbedtls_hmac_drbg_context *ctx)
Parameter	ctx: HMAC_DRBG context to free.
Return	None.
Description	Free an HMAC_DRBG context.
int mbedtls_hmac_drbg_reseed(mbedtls_hmac_drbg_context *ctx, const unsigned char *additional, size_t len)	
Prototype	int mbedtls_hmac_drbg_reseed(mbedtls_hmac_drbg_context *ctx, const unsigned char *additional, size_t len)
Parameter	ctx: HMAC_DRBG context. additional: Additional data to add to state (can be NULL). len: Length of additional data.
Return	0 if successful, or MBEDTLS_ERR_HMAC_DRBG_ENTROPY_SOURCE_FAILED.

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Item	Description
Description	HMAC_DRBG reseeding (extracts data from entropy source).

15.1.6.5 HMAC_DRBG Without Prediction Resistance

This example describes how to use HMAC_DRBG without prediction resistance.

```
int crypto_sample_hmac_drbg_pr_off()
{
      mbedtls_hmac_drbg_context ctx;
      const mbedtls_md_info_t *md_info = mbedtls_md_info_from_type(MBEDTLS_MD_SHA1);

      PRINTF("* HMAC_DRBG (PR = False) : ");

      // Initialize HMAC DRBG context.
      mbedtls_hmac_drbg_init(&ctx);

      // HMAC_DRBG initial seeding Seed and setup entropy source for future reseeds.
      ret = mbedtls_hmac_drbg_seed(&ctx, md_info,
                                   drbg_test_entropy,
                                   (void *)crypto_sample_hmac_drbg_entropy_src_nopr,
                                   NULL, 0);

      // HMAC_DRBG reseeding (extracts data from entropy source)
      ret = mbedtls_hmac_drbg_reseed(&ctx, NULL, 0);

      // Generate random.
      ret = mbedtls_hmac_drbg_random(&ctx, buf, CRYPTO_SAMPLE_HMAC_DRBG_OUTPUT_LEN);

      // Generate random.
      ret = mbedtls_hmac_drbg_random(&ctx, buf, CRYPTO_SAMPLE_HMAC_DRBG_OUTPUT_LEN);

      // Free an HMAC_DRBG context.
      mbedtls_hmac_drbg_free(&ctx);
}
```

15.1.7 Cryptographic Algorithms – ECDSA

The Elliptic Curve Digital Signature Algorithm sample application demonstrates common use cases of the Elliptic Curve Digital Signature Algorithm. In cryptography, the Elliptic Curve Digital Signature Algorithm (ECDSA) offers a variant of the Digital Signature Algorithm (DSA) which uses elliptic curve cryptography.

```
* Seeding the random number generator: passed
* Generating key pair: passed - (key size: 192 bits)
* Computing message hash: passed
* Signing message hash: passed - (signature length = 56)
* Preparing verification context: passed
* Verifying signature: passed
```

Figure 101: Result of Crypto ECDSA

15.1.7.1 Application Initialization

In cryptography, the ECDSA offers a variant of the DSA, which uses elliptic curve cryptography. This sample describes how the user uses the ECDSA of the “mbedTLS” library.

```
void crypto_sample_ecdsa(void *param)
{
```

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```
    crypto_sample_ecdsa_test();

    return ;
}
```

15.1.7.2 Generate ECDSA Key Pair and Verifies ECDSA Signature

This example generates an ECDSA keypair and verifies the self-computed ECDSA signature.

```
int crypto_sample_ecdsa_test()
{
    int ret = -1;

    const char *pers = "crypto_sample_ecdsa";

    mbedtls_ecdsa_context ctx_sign;
    mbedtls_ecdsa_context ctx_verify;
    mbedtls_entropy_context entropy;
    mbedtls_ctr_drbg_context ctr_drbg;
    mbedtls_sha256_context sha256_ctx;

    // Initialize an ECDSA context.
    mbedtls_ecdsa_init(&ctx_sign);
    mbedtls_ecdsa_init(&ctx_verify);

    // Initialize the CTR_DRBG context.
    mbedtls_ctr_drbg_init(&ctr_drbg);

    // Initialize the SHA-256 context.
    mbedtls_sha256_init(&sha256_ctx);

    // Initialize the entropy context.
    mbedtls_entropy_init(&entropy);

    memset(sig, 0x00, MBEDTLS_ECDSA_MAX_LEN);
    memset(message, 0x25, 100);

    // Generate a key pair for signing
    PRINTF("* Seeding the random number generator: ");

    // Seed and sets up the CTR_DRBG entropy source for future reseeds.
    ret = mbedtls_ctr_drbg_seed(&ctr_drbg, mbedtls_entropy_func, &entropy,
                                (const unsigned char *)pers, strlen(pers));


    PRINTF("* Generating key pair: ");
    // Generate an ECDSA keypair on the given curve.
    ret = mbedtls_ecdsa_genkey(&ctx_sign, MBEDTLS_ECP_DP_SECP192R1,
                                mbedtls_ctr_drbg_random, &ctr_drbg);

    // Compute message hash
    PRINTF("* Computing message hash: ");

    // Start a SHA-256 checksum calculation.
    mbedtls_sha256_starts_ret(&sha256_ctx, 0);

    // Feeds an input buffer into an ongoing SHA-256 checksum calculation.
    mbedtls_sha256_update_ret(&sha256_ctx, message, 100);

    // Finishe the SHA-256 operation, and writes the result to the output buffer.
    mbedtls_sha256_finish(&sha256_ctx, hash);
```

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```
    // Sign message hash
    PRINTF("* Signing message hash: ");

    // Compute the ECDSA signature and writes it to a buffer.
    ret = mbedtls_ecdsa_write_signature(&ctx_sign, MBEDTLS_MD_SHA256, hash, 32,
                          sig, &sig_len, mbedtls_ctr_drbg_random, &ctr_drbg);

    // Verify signature
    PRINTF("* Verifying signature: ");

    // Read and verify an ECDSA signature.
    ret = mbedtls_ecdsa_read_signature(&ctx_verify, hash, 32, sig, sig_len);

    // Free an ECDSA context.
    mbedtls_ecdsa_free(&ctx_verify);
    mbedtls_ecdsa_free(&ctx_sign);

    // Clear CTR_CRBG context data.
    mbedtls_ctr_drbg_free(&ctr_drbg);

    // Free the data in the context.
    mbedtls_entropy_free(&entropy);

    // Clear s SHA-256 context.
    mbedtls_sha256_free(&sha256_ctx);
}
```

The API details are as follows:

Table 43: APIs for ECDSA

Item	Description
void mbedtls_ecdsa_init(mbedtls_ecdsa_context *ctx)	
Prototype	void mbedtls_ecdsa_init(mbedtls_ecdsa_context *ctx)
Parameter	ctx: The ECDSA context to initialize. This must not be NULL.
Return	None.
Description	This function initializes an ECDSA context.
int mbedtls_ecdsa_genkey(mbedtls_ecdsa_context *ctx, mbedtls_ecp_group_id gid, int (*f_rng)(void *, unsigned char *, size_t), void *p_rng)	
Prototype	int mbedtls_ecdsa_genkey(mbedtls_ecdsa_context *ctx, mbedtls_ecp_group_id gid, int (*f_rng)(void *, unsigned char *, size_t), void *p_rng)
Parameter	ctx: The ECDSA context to store the keypair in. This must be initialized. gid: The elliptic curve to use. One of the various MBEDTLS_ECP_DP_XXX macros depending on configuration. f_rng: The RNG function to use. This must not be NULL. p_rng: The RNG context to be passed to f_rng. This may be NULL if f_rng does not need a context argument.
Return	0 on success. An MBEDTLS_ERR_ECP_XXX code on failure.
Description	This function generates an ECDSA keypair on the given curve.

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Item	Description
int mbedtls_ecdsa_write_signature(mbedtls_ecdsa_context *ctx, mbedtls_md_type_t md_alg, const unsigned char *hash, size_t hlen, unsigned char *sig, size_t *slen, int (*f_rng)(void *, unsigned char *, size_t), void *p_rng)	
Prototype	int mbedtls_ecdsa_write_signature(mbedtls_ecdsa_context *ctx, mbedtls_md_type_t md_alg, const unsigned char *hash, size_t hlen, unsigned char *sig, size_t *slen, int (*f_rng)(void *, unsigned char *, size_t), void *p_rng)
Parameter	ctx: The ECDSA context to use. This must be initialized and have a group and private key bound to it, for example via mbedtls_ecdsa_genkey() or mbedtls_ecdsa_from_keypair(). md_alg: The message digest that was used to hash the message. hash: The message hash to be signed. This must be a readable buffer of length hlen Bytes. hlen: The length of the hash in Bytes. sig: The buffer to which to write the signature. This must be a writable buffer of a length at least twice as large as the size of the curve used, plus 9. For example, 73 Bytes if a 256-bit curve is used. A buffer length of MBEDTLS_ECDSA_MAX_LEN is always safe. slen: The address at which to store the actual length of the signature written. Must not be NULL. f_rng: The RNG function. This must not be NULL if MBEDTLS_ECDSA_DETERMINISTIC is unset. Otherwise, it is unused and may be set to NULL. p_rng: The RNG context to be passed to f_rng. This may be NULL if f_rng is NULL or does not use a context.
Return	0 on success. An MBEDTLS_ERR_ECP_XXX, MBEDTLS_ERR_MPI_XXX or MBEDTLS_ERR_ASN1_XXX error code on failure.
Description	This function computes the ECDSA signature and writes it to a buffer, serialized as defined in RFC-4492: Elliptic Curve Cryptography (ECC) Cipher Suites for Transport Layer Security (TLS).
int mbedtls_ecdsa_read_signature(mbedtls_ecdsa_context *ctx, const unsigned char *hash, size_t hlen, const unsigned char *sig, size_t slen)	
Prototype	int mbedtls_ecdsa_read_signature(mbedtls_ecdsa_context *ctx, const unsigned char *hash, size_t hlen, const unsigned char *sig, size_t slen)
Parameter	ctx: The ECDSA context to use. This must be initialized and have a group and public key bound to it. hash: The message hash that was signed. This must be a readable buffer of length size Bytes. hlen: The size of the hash. sig: The signature to read and verify. This must be a readable buffer of length slen Bytes. slen: The size of sig in Bytes.
Return	0 on success. MBEDTLS_ERR_ECP_BAD_INPUT_DATA if signature is invalid. MBEDTLS_ERR_ECP_SIG_LEN_MISMATCH if there is a valid signature in sig, but its length is less than siglen. An MBEDTLS_ERR_ECP_XXX or MBEDTLS_ERR_MPI_XXX error code on failure for any other reason.
Description	This function reads and verifies an ECDSA signature.

15.1.8 Cryptographic Algorithms – Diffie-Hellman Key Exchange

The Diffie-Hellman-Merkle (DHM) key exchange sample application demonstrates common use cases of DHM key exchange on the client and server sides.

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```
* DHM parameter load: passed
* Diffie-Hellman full exchange: passed
```

Figure 102: Result of Crypto Diffie Hellman

15.1.8.1 Application Initialization

This example includes two types. The first, function crypto_sample_dhm_parse_dhm, shows how Diffie-Hellman parameters can be loaded. The second, function crypto_sample_dhm_do_dhm, shows how DA16200 works for Diffie-Hellman key exchange.

```
void crypto_sample_dhm()
{
    ret = crypto_sample_dhm_parse_dhm();

    for (idx = 0 ; crypto_sample_dhm_do_dhm_list[idx].title != NULL ; idx++) {
        ret = crypto_sample_dhm_do_dhm(crypto_sample_dhm_do_dhm_list[idx].title,
                                       crypto_sample_dhm_do_dhm_list[idx].radix_P,
                                       crypto_sample_dhm_do_dhm_list[idx].input_P,
                                       crypto_sample_dhm_do_dhm_list[idx].radix_G,
                                       crypto_sample_dhm_do_dhm_list[idx].input_G);
    }
}
```

15.1.8.2 How Diffie-Hellman Works

Sample codes and APIs show how the Diffie-Hellman works and is loaded over the “mbedTLS” library’s API. The API details are as follows:

Table 44: APIs for Diffie-Hellman-Merkle

Item	Description
void mbedtls_dhm_init(mbedtls_dhm_context *ctx)	
Prototype	void mbedtls_dhm_init(mbedtls_dhm_context *ctx) (Note 8)
Parameter	ctx: The DHM context to initialize.
Return	None.
Description	This function initializes the DHM context.
int mbedtls_dhm_parse_dhm(mbedtls_dhm_context *dhm, const unsigned char *dhmin, size_t dhminlen)	
Prototype	int mbedtls_dhm_parse_dhm(mbedtls_dhm_context *dhm, const unsigned char *dhmin, size_t dhminlen) (Note 8)
Parameter	dhm: The DHM context to import the DHM parameters into. This must be initialized. dhmin: The input buffer. This must be a readable buffer of length dhminlen Bytes. dhminlen: The size of the input buffer dhmin, including the terminating NULL Byte for PEM data.
Return	0 on success. An MBEDTLS_ERR_DHM_XXX or MBEDTLS_ERR_PEM_XXX error code on failure.
Description	This function parses DHM parameters in PEM or DER format.
void mbedtls_dhm_free(mbedtls_dhm_context *ctx)	
Prototype	void mbedtls_dhm_free(mbedtls_dhm_context *ctx) (Note 8)
Parameter	ctx: The DHM context to free and clear. This may be NULL, in which case this function is a no-op. If it is not NULL, it must point to an initialized DHM context.
Return	None.
Description	This function frees and clears the components of a DHM context.

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Item	Description
int mbedtls_dhm_make_params(mbedtls_dhm_context *ctx, int x_size, char *output, size_t *olen, int (*f_rng)(void *, unsigned char *, size_t), void *p_rng)	
Prototype	int mbedtls_dhm_make_params(mbedtls_dhm_context *ctx, int x_size, char *output, size_t *olen, int (*f_rng)(void *, unsigned char *, size_t), void *p_rng) (Note 9)
Parameter	ctx: The DHM context to use. This must be initialized and have the DHM parameters set. It may or may not already have imported the peer's public key. x_size: The private key size in Bytes. output: The destination buffer. This must be a writable buffer of sufficient size to hold the reduced binary presentation of the modulus, the generator and the public key, each wrapped with a 2-byte length field. It is the responsibility of the caller to ensure that enough space is available. See the mbedtls_mpi_size() to compute the byte-size of an MPI. olen: The address at which to store the number of Bytes written on success. This must not be NULL. f_rng: The RNG function. Must not be NULL. p_rng: The RNG context to be passed to f_rng. This may be NULL if f_rng does not need a context parameter.
Return	0 on success. An MBEDTLS_ERR_DHM_XXX error code on failure.
Description	This function generates a DHM key pair and exports its public part together with the DHM parameters in the format used in a TLS ServerKeyExchange handshake message.
int mbedtls_dhm_read_params(mbedtls_dhm_context *ctx, unsigned char **p, unsigned char *end)	
Prototype	int mbedtls_dhm_read_params(mbedtls_dhm_context *ctx, unsigned char **p, unsigned char *end) (Note 9)
Parameter	ctx: The DHM context to use. This must be initialized. p: On input, *p must be the start of the input buffer. On output, *p is updated to point to the end of the data that has been read. On success, this is the first byte past the end of the ServerKeyExchange parameters. On error, this is the point at which an error has been detected, which is usually not useful except to debug failures. end: The end of the input buffer.
Return	0 on success. An MBEDTLS_ERR_DHM_XXX error code on failure.
Description	This function parses the DHM parameters in a TLS ServerKeyExchange handshake message (DHM modulus, generator, and public key).
int mbedtls_dhm_make_public(mbedtls_dhm_context *ctx, int x_size, unsigned char *output, size_t olen, int (*f_rng)(void *, unsigned char *, size_t), void *p_rng)	
Prototype	int mbedtls_dhm_read_params(mbedtls_dhm_context *ctx, unsigned char **p, unsigned char *end) (Note 9)
Parameter	ctx: The DHM context to use. This must be initialized. p: On input, *p must be the start of the input buffer. On output, *p is updated to point to the end of the data that has been read. On success, this is the first byte past the end of the ServerKeyExchange parameters. On error, this is the point at which an error has been detected, which is usually not useful except to debug failures. end: The end of the input buffer.
Return	0 on success. An MBEDTLS_ERR_DHM_XXX error code on failure.
Description	This function parses the DHM parameters in a TLS ServerKeyExchange handshake message (DHM modulus, generator, and public key).
int mbedtls_dhm_make_public(mbedtls_dhm_context *ctx, int x_size, unsigned char *output, size_t olen, int (*f_rng)(void *, unsigned char *, size_t), void *p_rng)	
Prototype	int mbedtls_dhm_make_public(mbedtls_dhm_context *ctx, int x_size, unsigned char *output, size_t olen, int (*f_rng)(void *, unsigned char *, size_t), void *p_rng) (Note 9)

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Item	Description
Parameter	ctx: The DHM context to use. This must be initialized and have the DHM parameters set. It may or may not already have imported the peer's public key. x_size: The private key size in Bytes. output: The destination buffer. This must be a writable buffer of size olen Bytes. olen: The length of the destination buffer. This must be at least equal to ctx->len (the size of P). f_rng: The RNG function. This must not be NULL. p_rng: The RNG context to be passed to f_rng. This may be NULL if f_rng does not need a context argument.
Return	0 on success. An MBEDTLS_ERR_DHM_XXX error code on failure.
Description	This function creates a DHM key pair and exports the raw public key in big-endian format.
int mbedtls_dhm_read_public(mbedtls_dhm_context *ctx, const unsigned char *input, size_t ilen)	
Prototype	int mbedtls_dhm_read_public(mbedtls_dhm_context *ctx, const unsigned char *input, size_t ilen) (Note 9)
Parameter	ctx: The DHM context to use. This must be initialized and have its DHM parameters set, for instance via mbedtls_dhm_set_group(). It may or may not already have generated its own private key. input: The input buffer containing the G^Y value of the peer. This must be a readable buffer of size ilen Bytes. ilen: The size of the input buffer input in Bytes.
Return	0 on success. An MBEDTLS_ERR_DHM_XXX error code on failure.
Description	This function imports the raw public value of the peer.
int mbedtls_dhm_calc_secret(mbedtls_dhm_context *ctx, unsigned char *output, size_t output_size, size_t *olen, int (*f_rng)(void *, unsigned char *, size_t), void *p_rng)	
Prototype	int mbedtls_dhm_calc_secret(mbedtls_dhm_context *ctx, unsigned char *output, size_t output_size, size_t *olen, int (*f_rng)(void *, unsigned char *, size_t), void *p_rng) (Note 9)
Parameter	ctx: The DHM context to use. This must be initialized and have its own private key generated and the peer's public key imported. output: The buffer to write the generated shared key to. This must be a writable buffer of size output_size Bytes. output_size: The size of the destination buffer. This must be at least the size of ctx->len (the size of P). olen: On exit, holds the actual number of Bytes written. f_rng: The RNG function, for blinding purposes. This may be NULL if blinding is not needed. p_rng: The RNG context. This may be NULL if f_rng does not need a context argument.
Return	0 on success. An MBEDTLS_ERR_DHM_XXX error code on failure.
Description	This function derives and exports the shared secret (G^Y)^X mod P.

Note 8 How to Load Diffie-Hellman Parameters

The mbedtls_dhm_parse_dhm parses DHM parameters in PEM or DER format. The crypto_sample_dhm_params is already defined in this sample.

```
int crypto_sample_dhm_parse_dhm()
{
    mbedtls_dhm_context *dhm = NULL;     // The DHM context structure.
```

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```
    // Initialize the DHM context.
    mbedtls_dhm_init(dhm);

    // Parse DHM parameters in PEM or DER format.
    ret = mbedtls_dhm_parse_dhm(dhm,
                                (const unsigned char *)crypto_sample_dhm_params,
                                crypto_sample_dhm_params_len);

    // Free and clear the components of a DHM context.
    mbedtls_dhm_free(dhm);
}
```

Note 9 How Diffie-Hellman Works

The sample code shows how Diffie-Hellman works over the API of the “mbedTLS” library. Diffie-Hellman operation is normally used during TLS Handshake, ServerKeyExchange, and ClientKeyExchange messages. To verify it, the code exchanges ServerKeyExchange and ClientKeyExchange messages.

```
int crypto_sample_dhm_do_dhm(char *title, int radix_P, char *input_P, int radix_G,
char *input_G)
{
    mbedtls_dhm_context ctx_srv;
    mbedtls_dhm_context ctx_cli;
    rnd_pseudo_info rnd_info;

    // Initialize the DHM context.
    mbedtls_dhm_init(&ctx_srv);
    mbedtls_dhm_init(&ctx_cli);

    // Set parameters
    MBEDTLS_MPI_CHK(mbedtls_mpi_read_string(&ctx_srv.P, radix_P, input_P));
    MBEDTLS_MPI_CHK(mbedtls_mpi_read_string(&ctx_srv.G, radix_G, input_G));

    x_size = mbedtls_mpi_size(&ctx_srv.P);
    pub_cli_len = x_size;

    /* Generate a DHM key pair and export its public part together
     * with the DHM parameters in the format.
     */
    ret = mbedtls_dhm_make_params(&ctx_srv, x_size, ske, &ske_len,
                                  &rnd_pseudo_rand, &rnd_info);

    // Parse the DHM parameters (DHM modulus, generator, and public key)
    ret = mbedtls_dhm_read_params(&ctx_cli, &p, ske + ske_len);

    // Create a DHM key pair and export the raw public key in big-endian format.
    ret = mbedtls_dhm_make_public(&ctx_cli, x_size, pub_cli, pub_cli_len,
                                  &rnd_pseudo_rand, &rnd_info);

    // Import the raw public value of the peer.
    ret = mbedtls_dhm_read_public(&ctx_srv, pub_cli, pub_cli_len);

    // Derive and export the shared secret (G^Y)^X mod P.
    ret = mbedtls_dhm_calc_secret(&ctx_srv, sec_srv, DHM_BUF_SIZE,
                                  &sec_srv_len, &rnd_pseudo_rand, &rnd_info);

    // Derive and export the shared secret (G^Y)^X mod P.
    ret = mbedtls_dhm_calc_secret(&ctx_cli, sec_cli, DHM_BUF_SIZE, &sec_cli_len,
                                  NULL, NULL);
```

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```
    // Free and clear the components of a DHM context.
    mbedtls_dhm_free(&ctx_srv);
    mbedtls_dhm_free(&ctx_cli);
}
```

15.1.9 Cryptographic Algorithms – RSA PKCS#1

The RSA PKCS#1 sample application demonstrates common use cases of RSA PKCS#1 functions.

```
* RSA key validation: passed
* PKCS#1 encryption : passed
* PKCS#1 decryption : passed
* PKCS#1 data sign  : passed
* PKCS#1 sig. verify: passed
```

Figure 103: Result of Crypto RSA

15.1.9.1 Application Initialization

This example shows RSA key validation, encryption, decryption, and verification of the signature. To verify the signature, a SHA-1 Hash algorithm is used.

```
void crypto_sample_rsa(ULONG arg)
{
    crypto_sample_rsa_pkcs1();

    return ;
}
```

15.1.9.2 How RSA PKCS#1 Works

The example application below shows how RSA PKCS#1 works over the API of the “mbedTLS” library. To verify, an RSA-1024 keypair and a SHA-1 Hash algorithm are used on RSA PKCS-1 v1.5.

```
int crypto_sample_rsa_pkcs1()
{
    mbedtls_rsa_context *rsa = NULL;        // The RSA context structure.
    unsigned char *sha1sum = NULL;

    // Initializes an RSA context.
    mbedtls_rsa_init(rsa, MBEDTLS_RSA_PKCS_V15, MBEDTLS_MD_NONE);

    PRINTF("* RSA key validation: ");

    // Check if a context contains at least an RSA public key.
    ret = mbedtls_rsa_check_pubkey(rsa);

    ret = mbedtls_rsa_check_privkey(rsa);

    PRINTF("* PKCS#1 encryption : ");

    memcpy(rsa_plaintext, RSA_PT, PT_LEN);

    // Add the message padding, then performs an RSA operation.
    ret = mbedtls_rsa_pkcs1_encrypt(rsa, myrand,
                                    NULL, MBEDTLS_RSA_PUBLIC, PT_LEN,
                                    rsa_plaintext, rsa_ciphertext);

    PRINTF("* PKCS#1 decryption : ");

    // Perform an RSA operation, then removes the message padding.
    ret = mbedtls_rsa_pkcs1_decrypt(rsa, myrand,
                                    NULL, MBEDTLS_RSA_PRIVATE, &len,
                                    rsa_ciphertext, rsa_decrypted,
```

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```
                                    (PT_LEN * sizeof(unsigned char)));

    PRINTF("* PKCS#1 data sign  : ");

    mbedtls_sha1_ret(rsa_plaintext, PT_LEN, sha1sum);

    // Perform a private RSA operation to sign a message digest using PKCS#1.
    ret = mbedtls_rsa_pkcs1_sign(rsa, myrand,
                                 NULL, MBEDTLS_RSA_PRIVATE, MBEDTLS_MD_SHA1,
                                 0, sha1sum, rsa_ciphertext);


    PRINTF("* PKCS#1 sig. verify: ");

    // Perform a public RSA operation and checks the message digest.
    ret = mbedtls_rsa_pkcs1_verify(rsa, NULL,
                                   NULL, MBEDTLS_RSA_PUBLIC, MBEDTLS_MD_SHA1,
                                   0, sha1sum, rsa_ciphertext);

    // Free the components of an RSA key.
    mbedtls_rsa_free(rsa);
}
```

The API details are as follows.

Table 45: APIs for PKCS#11 RSA

Item	Description
void mbedtls_rsa_init(mbedtls_rsa_context *ctx, int padding, int hash_id)	
Prototype	void mbedtls_rsa_init(mbedtls_rsa_context *ctx, int padding, int hash_id)
Parameter	ctx: The RSA context to initialize. This must not be NULL. padding: The padding mode to use. This must be either MBEDTLS_RSA_PKCS_V15 or MBEDTLS_RSA_PKCS_V21. hash_id: The hash identifier of mbedtls_md_type_t type, if padding is MBEDTLS_RSA_PKCS_V21. It is otherwise unused.
Return	None.
Description	This function initializes an RSA context.
int mbedtls_rsa_check_pubkey(const mbedtls_rsa_context *ctx)	
Prototype	int mbedtls_rsa_check_pubkey(const mbedtls_rsa_context *ctx)
Parameter	ctx: The initialized RSA context to check.
Return	0 on success. An MBEDTLS_ERR_RSA_XXX error code on failure.
Description	This function checks if a context contains at least an RSA public key. If the function runs successfully, it is guaranteed that enough information is present to do an RSA public key operation with mbedtls_rsa_public().
int mbedtls_rsa_check_privkey(const mbedtls_rsa_context *ctx)	
Prototype	int mbedtls_rsa_check_pubkey(const mbedtls_rsa_context *ctx)
Parameter	ctx: The initialized RSA context to check.
Return	0 on success. An MBEDTLS_ERR_RSA_XXX error code on failure.
Description	This function checks if a context contains an RSA private key and does basic consistency checks.

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Item	Description
int mbedtls_rsa_pkcs1_encrypt(mbedtls_rsa_context *ctx, int (*f_rng)(void *, unsigned char *, size_t), void *p_rng, int mode, size_t ilen, const unsigned char *input, unsigned char *output)	
Prototype	int mbedtls_rsa_pkcs1_encrypt(mbedtls_rsa_context *ctx, int (*f_rng)(void *, unsigned char *, size_t), void *p_rng, int mode, size_t ilen, const unsigned char *input, unsigned char *output)
Parameter	ctx: The initialized RSA context to use. f_rng: The RNG to use. It is mandatory for PKCS#1 v2.1 padding encoding, and for PKCS#1 v1.5 padding encoding when used with mode set to MBEDTLS_RSA_PUBLIC. For PKCS#1 v1.5 padding encoding and mode set to MBEDTLS_RSA_PRIVATE, it is used for blinding and should be provided in this case. See mbedtls_rsa_private() for more information. p_rng: The RNG context to be passed to f_rng. May be NULL if f_rng is NULL or if f_rng does not need a context argument. mode: The mode of operation. This must be either MBEDTLS_RSA_PUBLIC or MBEDTLS_RSA_PRIVATE (deprecated). ilen: The length of the plaintext in Bytes. input: The input data to encrypt. This must be a readable buffer of size ilen Bytes. This must not be NULL. output: The output buffer. This must be a writable buffer of length ctx->len Bytes. For example, 256 Bytes for a 2048-bit RSA modulus.
Return	0 on success. An MBEDTLS_ERR_RSA_XXX error code on failure.
Description	This function adds the message padding, then does an RSA operation. It is the generic wrapper to do a PKCS#1 encryption operation with the mode from the context.
int mbedtls_rsa_pkcs1_decrypt(mbedtls_rsa_context *ctx, int (*f_rng)(void *, unsigned char *, size_t), void *p_rng, int mode, size_t *olen, const unsigned char *input, unsigned char *output, size_t output_max_len)	
Prototype	int mbedtls_rsa_pkcs1_decrypt(mbedtls_rsa_context *ctx, int (*f_rng)(void *, unsigned char *, size_t), void *p_rng, int mode, size_t *olen, const unsigned char *input, unsigned char *output, size_t output_max_len)
Parameter	ctx: The initialized RSA context to use. f_rng: The RNG function. If mode is MBEDTLS_RSA_PRIVATE, this is used for blinding and should be provided; see mbedtls_rsa_private() for more. If mode is MBEDTLS_RSA_PUBLIC, it is ignored. p_rng: The RNG context to be passed to f_rng. This may be NULL if f_rng is NULL or does not need a context. mode: The mode of operation. This must be either MBEDTLS_RSA_PRIVATE or MBEDTLS_RSA_PUBLIC (deprecated). olen: The address at which to store the length of the plaintext. This must not be NULL. input: The ciphertext buffer. This must be a readable buffer of length ctx->len Bytes. For example, 256 Bytes for a 2048-bit RSA modulus. output: The buffer used to hold the plaintext. This must be a writable buffer of length output_max_len Bytes. output_max_len: The length in Bytes of the output buffer output.
Return	0 on success. An MBEDTLS_ERR_RSA_XXX error code on failure.
Description	This function does an RSA operation, then removes the message padding. It is the generic wrapper to do a PKCS#1 decryption operation with the mode from the context.

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Item	Description
int mbedtls_rsa_pkcs1_sign(mbedtls_rsa_context *ctx, int (*f_rng)(void *, unsigned char *, size_t), void *p_rng, int mode, mbedtls_md_type_t md_alg, unsigned int hashlen, const unsigned char *hash, unsigned char *sig)	
Prototype	int mbedtls_rsa_pkcs1_sign(mbedtls_rsa_context *ctx, int (*f_rng)(void *, unsigned char *, size_t), void *p_rng, int mode, mbedtls_md_type_t md_alg, unsigned int hashlen, const unsigned char *hash, unsigned char *sig)
Parameter	ctx: The initialized RSA context to use. f_rng: The RNG function to use. If the padding mode is PKCS#1 v2.1, this must be provided. If the padding mode is PKCS#1 v1.5 and the mode is MBEDTLS_RSA_PRIVATE, it is used for blinding and should be provided. See mbedtls_rsa_private() for more information. It is otherwise ignored. p_rng: The RNG context to be passed to f_rng. This may be NULL if f_rng is NULL or does not need a context argument. mode: The mode of operation. This must be either MBEDTLS_RSA_PRIVATE or MBEDTLS_RSA_PUBLIC (deprecated). md_alg: The message-digest algorithm used to hash the original data. Use MBEDTLS_MD_NONE for signing raw data. hashlen: The length of the message digest. This is only used if md_alg is MBEDTLS_MD_NONE. hash: The buffer holding the message digest or raw data. If md_alg is MBEDTLS_MD_NONE, this must be a readable buffer of length hashlen Bytes. If md_alg is not MBEDTLS_MD_NONE, it must be a readable buffer of length the size of the hash corresponding to md_alg. sig: The buffer to hold the signature. This must be a writable buffer of length ctx->len Bytes. For example, 256 Bytes for a 2048-bit RSA modulus.
Return	0 on success. An MBEDTLS_ERR_RSA_XXX error code on failure.
Description	This function does a private RSA operation to sign a message digest with PKCS#1. It is the generic wrapper to do a PKCS#1 signature with the mode from the context.
int mbedtls_rsa_pkcs1_verify(mbedtls_rsa_context *ctx, int (*f_rng)(void *, unsigned char *, size_t), void *p_rng, int mode, mbedtls_md_type_t md_alg, unsigned int hashlen, const unsigned char *hash, const unsigned char *sig)	
Prototype	int mbedtls_rsa_pkcs1_verify(mbedtls_rsa_context *ctx, int (*f_rng)(void *, unsigned char *, size_t), void *p_rng, int mode, mbedtls_md_type_t md_alg, unsigned int hashlen, const unsigned char *hash, const unsigned char *sig)
Parameter	ctx: The initialized RSA public key context to use. f_rng: The RNG function to use. If mode is MBEDTLS_RSA_PRIVATE, this is used for blinding and should be provided; see mbedtls_rsa_private() for more. Otherwise, it is ignored. p_rng: The RNG context to be passed to f_rng. This may be NULL if f_rng is NULL or does not need a context. mode: The mode of operation. This must be either MBEDTLS_RSA_PUBLIC or MBEDTLS_RSA_PRIVATE (deprecated). md_alg: The message-digest algorithm used to hash the original data. Use MBEDTLS_MD_NONE for signing raw data. hashlen: The length of the message digest. This is only used if md_alg is MBEDTLS_MD_NONE. hash: The buffer holding the message digest or raw data. If md_alg is MBEDTLS_MD_NONE, this must be a readable buffer of length hashlen Bytes. If md_alg is not MBEDTLS_MD_NONE, it must be a readable buffer of length the size of the hash that corresponds to md_alg. sig: The buffer holding the signature. This must be a readable buffer of length ctx->len Bytes. For example, 256 Bytes for a 2048-bit RSA modulus.
Return	0 on success. An MBEDTLS_ERR_RSA_XXX error code on failure.

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Item	Description
Description	This function does a public RSA operation and checks the message digest. This is the generic wrapper to do PKCS#1 verification with the mode from the context.
void mbedtls_rsa_free(mbedtls_rsa_context *ctx)	
Prototype	void mbedtls_rsa_free(mbedtls_rsa_context *ctx)
Parameter	ctx: The RSA context to free. May be NULL, in which case this function is a no-op. If it is not NULL, it must point to an initialized RSA context.
Return	None.
Description	This function frees the components of an RSA key.

15.1.10 Cryptographic Algorithms – ECDH

The Elliptic-curve Diffie-Hellman (ECDH) sample application demonstrates common use cases of ECDH key exchange. It is a variant of the Diffie-Hellman protocol that uses elliptic-curve cryptography.

```
>>> Using Elliptic Curve: SECP224R1
* Seeding the random number generator: passed
* Setting up client context: passed
* Setting up server context: passed
* Server reading client key and computing secret: passed
* Client reading server key and computing secret: passed
* Checking if both computed secrets are equal: passed

>>> Using Elliptic Curve: SECP256R1
* Seeding the random number generator: passed
* Setting up client context: passed
* Setting up server context: passed
* Server reading client key and computing secret: passed
* Client reading server key and computing secret: passed
* Checking if both computed secrets are equal: passed

>>> Using Elliptic Curve: SECP384R1
* Seeding the random number generator: passed
* Setting up client context: passed
* Setting up server context: passed
* Server reading client key and computing secret: passed
* Client reading server key and computing secret: passed
* Checking if both computed secrets are equal: passed

>>> Using Elliptic Curve: SECP521R1
* Seeding the random number generator: passed
* Setting up client context: passed
* Setting up server context: passed
* Server reading client key and computing secret: passed
* Client reading server key and computing secret: passed
* Checking if both computed secrets are equal: passed
```

Figure 104: Result of Crypto ECDH

15.1.10.1 Application Initialization

This example describes how the ECDH key exchange works with the use of Elliptic Curve SECP224R1, SECP256R1, SECP384R1, SECP521R1, and Curve25519.

```
void crypto_sample_ecdh(void *param)
{
    mbedtls_ecp_group_id ids[6] = {
        MBEDTLS_ECP_DP_SECP224R1, /*!< 224-bits NIST curve  */
        MBEDTLS_ECP_DP_SECP256R1, /*!< 256-bits NIST curve  */
        MBEDTLS_ECP_DP_SECP384R1, /*!< 384-bits NIST curve  */
        MBEDTLS_ECP_DP_SECP521R1, /*!< 521-bits NIST curve  */
        MBEDTLS_ECP_DP_CURVE25519,/*!< Curve25519           */
```

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```
        MBEDTLS_ECP_DP_NONE
    };

    for (idx = 0, id = ids[idx] ; idx < 6 && id != MBEDTLS_ECP_DP_NONE ; idx++,
         id = ids[idx])
    {
        ret = crypto_sample_ecdh_key_exchange(id);
        if (ret) {
            break;
        }
    }
}
```

15.1.10.2 How ECDH Key Exchange Works

This sample application shows how ECDH works over the API of the “mbedTLS” library. In this example, the ECDH key exchange is verified on the server and client sides.

```
int crypto_sample_ecdh_key_exchange(mbedtls_ecp_group_id id)
{
    mbedtls_ecdh_context ctx_cli;
    mbedtls_ecdh_context ctx_srv;
    mbedtls_entropy_context entropy;
    mbedtls_ctr_drbg_context ctr_drbg;

    // Initialize an ECDH context.
    mbedtls_ecdh_init(&ctx_cli);
    mbedtls_ecdh_init(&ctx_srv);

    // Initialize the CTR_DRBG context.
    mbedtls_ctr_drbg_init(&ctr_drbg);

    // Initialize the entropy context.
    mbedtls_entropy_init(&entropy);

    PRINTF( ">>> Using Elliptic Curve: ");

    switch (id) {
        case MBEDTLS_ECP_DP_SECP224R1: {
            PRINTF("SECP224R1\r\n");
        }
        break;
        case MBEDTLS_ECP_DP_SECP256R1: {
            PRINTF("SECP256R1\r\n");
        }
        break;
        case MBEDTLS_ECP_DP_SECP384R1: {
            PRINTF("SECP384R1\r\n");
        }
        break;
        case MBEDTLS_ECP_DP_SECP521R1: {
            PRINTF("SECP521R1\r\n");
        }
        break;
        case MBEDTLS_ECP_DP_CURVE25519: {
            PRINTF("Curve25519\r\n");
        }
        break;
        default: {
            PRINTF("failed - [%s] Invalid Curve selected!\r\n");
        }
```

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```
        goto cleanup;
    }
    // Initialize random number generation
    PRINTF("* Seeding the random number generator: ");

    ret = mbedtls_ctr_drbg_seed(&ctr_drbg, mbedtls_entropy_func, &entropy,
                                (const unsigned char *)pers, sizeof(pers));

    // Client: inialize context and generate keypair
    PRINTF("* Setting up client context: ");

    // Sets up an ECP group context from a standardized set of domain parameters.
    ret = mbedtls_ecp_group_load(&(ctx_cli.grp), id);

    // Generate an ECDH keypair on an elliptic curve.
    ret = mbedtls_ecdh_gen_public(&(ctx_cli.grp), &(ctx_cli.d), &(ctx_cli.Q),
                                  mbedtls_ctr_drbg_random, &ctr_drbg);
    /* Export multi-precision integer (MPI) into unsigned binary data,
     * big endian (X coordinate of ECP point)
     */
    MBEDTLS_MPI_CHK(mbedtls_mpi_write_binary(&(ctx_cli.Q.X), cli_to_srv_x, buflen));

    /* Export multi-precision integer (MPI) into unsigned binary data,
     * big endian (Y coordinate of ECP point)
     */
    MBEDTLS_MPI_CHK(mbedtls_mpi_write_binary(&(ctx_cli.Q.Y), cli_to_srv_y, buflen));

    // Server: initialize context and generate keypair
    PRINTF("* Setting up server context: ");

    // Sets up an ECP group context from a standardized set of domain parameters.
    ret = mbedtls_ecp_group_load(&(ctx_srv.grp), id);

    // Generate a public key
    ret = mbedtls_ecdh_gen_public(&(ctx_srv.grp), &(ctx_srv.d), &(ctx_srv.Q),
                                  mbedtls_ctr_drbg_random, &ctr_drbg);

    /* Export multi-precision integer (MPI) into unsigned binary data,
     * big endian (X coordinate of ECP point).
     */
    MBEDTLS_MPI_CHK(mbedtls_mpi_write_binary(&(ctx_srv.Q.X), srv_to_cli_x, buflen));

    /* Export multi-precision integer (MPI) into unsigned binary data,
     * big endian (Y coordinate of ECP point).
     */

    MBEDTLS_MPI_CHK(mbedtls_mpi_write_binary(&(ctx_srv.Q.Y), srv_to_cli_y, buflen));
    /*
     * Server: read peer's key and generate shared secret
     */
    // Set the Z component of the peer's public value (public key) to 1
    MBEDTLS_MPI_CHK(mbedtls_mpi_lset(&(ctx_srv.Qp.Z), 1));

    /* Set the X component of the peer's public value based on
     * what was passed from client in the buffer.
     */
    MBEDTLS_MPI_CHK(mbedtls_mpi_read_binary(&(ctx_srv.Qp.X), cli_to_srv_x, buflen));

    /* Set the Y component of the peer's public value based on
     * what was passed from client in the buffer.
```

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```
     */
    MBEDTLS_MPI_CHK(mbedtls_mpi_read_binary(&(ctx_srv.Qp.Y), cli_to_srv_y, buflen));

    // Compute the shared secret.
    ret = mbedtls_ecdh_compute_shared(&(ctx_srv.grp),
                                      &(ctx_srv.z), &(ctx_srv.Qp), &(ctx_srv.d),
                                      mbedtls_ctr_drbg_random, &ctr_drbg);

    // Client: read peer's key and generate shared secret
    PRINTF("* Client reading server key and computing secret: ");

    MBEDTLS_MPI_CHK(mbedtls_mpi_lset(&(ctx_cli.Qp.Z), 1));

    MBEDTLS_MPI_CHK(mbedtls_mpi_read_binary(&(ctx_cli.Qp.X), srv_to_cli_x, buflen));

    MBEDTLS_MPI_CHK(mbedtls_mpi_read_binary(&(ctx_cli.Qp.Y), srv_to_cli_y, buflen));

    // Compute the shared secret.
    ret = mbedtls_ecdh_compute_shared(&(ctx_cli.grp), &(ctx_cli.z),
                                      &(ctx_cli.Qp), &(ctx_cli.d),
                                      mbedtls_ctr_drbg_random, &ctr_drbg);

    // Verification: are the computed secrets equal?
    PRINTF("* Checking if both computed secrets are equal: ");

    MBEDTLS_MPI_CHK(mbedtls_mpi_cmp_mpi(&(ctx_cli.z), &(ctx_srv.z)));

    // Free ECDH context.
    mbedtls_ecdh_free(&ctx_cli);
    mbedtls_ecdh_free(&ctx_srv);

    // Free the data in the context.
    mbedtls_entropy_free(&entropy);

    // Clear CTR_CRBG context data.
    mbedtls_ctr_drbg_free(&ctr_drbg);
}
```

The API details are as follows:

Table 46: APIs for ECDH

Item	Description
void mbedtls_ecdh_init(mbedtls_ecdh_context *ctx)	
Prototype	void mbedtls_ecdh_init(mbedtls_ecdh_context *ctx)
Parameter	ctx: The ECDH context to initialize. This must not be NULL.
Return	None.
Description	This function initializes an ECDH context.
int mbedtls_ecp_group_load(mbedtls_ecp_group *grp, mbedtls_ecp_group_id id)	
Prototype	int mbedtls_ecp_group_load(mbedtls_ecp_group *grp, mbedtls_ecp_group_id id)
Parameter	grp: The group context to set up. This must be initialized. id: The identifier of the domain parameter set to load.
Return	0 on success. MBEDTLS_ERR_ECP_FEATURE_UNAVAILABLE if the id does not correspond to a known group. Another negative error code on other kinds of failure.
Description	This function sets up an ECP group context from a standardized set of domain parameters.

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Item	Description
int mbedtls_ecdh_gen_public(mbedtls_ecp_group *grp, mbedtls_mpi *d, mbedtls_ecp_point *Q, int (*f_rng)(void *, unsigned char *, size_t), void *p_rng)	
Prototype	int mbedtls_ecdh_gen_public(mbedtls_ecp_group *grp, mbedtls_mpi *d, mbedtls_ecp_point *Q, int (*f_rng)(void *, unsigned char *, size_t), void *p_rng)
Parameter	grp: The ECP group to use. This must be initialized and have domain parameters loaded, for example through mbedtls_ecp_load() or mbedtls_ecp_tls_read_group(). d: The destination MPI (private key). This must be initialized. Q: The destination point (public key). This must be initialized. f_rng: The RNG function to use. This must not be NULL. p_rng: The RNG context to be passed to f_rng. This may be NULL in case f_rng does not need a context argument.
Return	0 on success. Another MBEDTLS_ERR_ECP_XXX or MBEDTLS_MPI_XXX error code on failure.
Description	This function generates an ECDH keypair on an elliptic curve. This function does the first of two core computations implemented during the ECDH key exchange. The second core computation is done by mbedtls_ecdh_compute_shared().
int mbedtls_ecdh_compute_shared(mbedtls_ecp_group *grp, mbedtls_mpi *z, const mbedtls_ecp_point *Q, const mbedtls_mpi *d, int (*f_rng)(void *, unsigned char *, size_t), void *p_rng)	
Prototype	int mbedtls_ecdh_compute_shared(mbedtls_ecp_group *grp, mbedtls_mpi *z, const mbedtls_ecp_point *Q, const mbedtls_mpi *d, int (*f_rng)(void *, unsigned char *, size_t), void *p_rng)
Parameter	grp: The ECP group to use. This must be initialized and have domain parameters loaded, for example through mbedtls_ecp_load() or mbedtls_ecp_tls_read_group(). z: The destination MPI (shared secret). This must be initialized. Q: The public key from another party. This must be initialized. d: Our secret exponent (private key). This must be initialized. f_rng: The RNG function. This may be NULL if randomization of intermediate results during the ECP computations is not needed (discouraged). See the documentation of mbedtls_ecp_mul() for more information. p_rng: The RNG context to be passed to f_rng. This may be NULL if f_rng is NULL or does not need a context argument.
Return	0 on success. Another MBEDTLS_ERR_ECP_XXX or MBEDTLS_MPI_XXX error code on failure.
Description	This function computes the shared secret. This function does the second of two core computations implemented during the ECDH key exchange. The first core computation is done by mbedtls_ecdh_gen_public().
void mbedtls_ecdh_free(mbedtls_ecdh_context *ctx)	
Prototype	void mbedtls_ecdh_free(mbedtls_ecdh_context *ctx)
Parameter	ctx: The context to free. This may be NULL, in which case this function does nothing. If it is not NULL, it must point to an initialized ECDH context.
Return	None.
Description	This function frees a context.

15.1.11 Cryptographic Algorithms – KDF

The Key Derivation Function (KDF) sample application demonstrates common use cases of PKCS#5 functions.

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```
* PBKDF2 (SHA1): passed
```

Figure 105: Result of Crypto KDF

15.1.11.1 Application Initialization

This example uses a password-based Key Derivation Function specified in PKCS#5 PBKDF2 and implemented in "mbedTLS" in function mbedtls_pkcs5_pdkdf2_hmac.

```
void crypto_sample_kdf(void *param)
{
    crypto_sample_pkcs5();
}
```

15.1.11.2 How KDF Works

This example application shows how KDF works over the API of the "mbedTLS" library. In this example, PKCS#5 PBKDF2 is used. To verify, a SHA-1 Hash algorithm is used.

```
int crypto_sample_pkcs5()
{
    mbedtls_md_context_t sha1_ctx;
    const mbedtls_md_info_t *info_sha1;

    // Initialize a SHA-1 context.
    mbedtls_md_init(&sha1_ctx);

    // Get the message-digest information associated with the given digest type.
    info_sha1 = mbedtls_md_info_from_type(MBEDTLS_MD_SHA1);

    // Select the message digest algorithm to use, and allocate internal
    // structures.
    ret = mbedtls_md_setup(&sha1_ctx, info_sha1, 1);

    PRINTF("* PBKDF2 (SHA1): ");

    // Derive a key from a password using PBKDF2 function with HMAC
    ret = mbedtls_pkcs5_pbkdf2_hmac(&sha1_ctx,
                                    pkcs5_password, pkcs5_plen,
                                    pkcs5_salt, pkcs5_slen,
                                    pkcs5_it_cnt,
                                    pkcs5_key_len, key);

    /* Clear the internal structure of ctx and free any embedded internal
       structure,
     * but does not free ctx itself.
     */
    mbedtls_md_free(&sha1_ctx);
}
```

The API details are as follows.

Table 47: APIs for PKCS#5 PBKDF2

Item	Description
int mbedtls_pkcs5_pbkdf2_hmac(mbedtls_md_context_t *ctx, const unsigned char *password, size_t plen, const unsigned char *salt, size_t slen, unsigned int iteration_count, uint32_t key_length, unsigned char *output)	
Prototype	int mbedtls_pkcs5_pbkdf2_hmac(mbedtls_md_context_t *ctx, const unsigned char *password, size_t plen, const unsigned char *salt, size_t slen, unsigned int iteration_count, uint32_t key_length, unsigned char *output)

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Item	Description
Parameter	ctx: Generic HMAC context. password: Password to use when generating a key. plen: Length of password. salt: Salt to use when generating a key. slen: Length of salt. iteration_count: Iteration count. key_length: Length of generated key in bytes. output: Generated key. Must be at least as big as key_length.
Return	0 on success, or a MBEDTLS_ERR_XXX code if verification fails.
Description	PKCS#5 PBKDF2 using HMAC.

15.1.12 Cryptographic Algorithms – Public Key Abstraction Layer

The "mbedTLS" library provides the Public Key abstraction layer for confidentiality, integrity, authentication, and non-repudiation based on asymmetric algorithms, using traditional RSA or Elliptic Curves. The Public Key abstraction layer sample application demonstrates common use cases of the APIs.

```
* PK Information
>>> RSA: passed
>>> EC: passed
>>> EC_DH: passed
>>> ECDSA: passed
* RSA Verification Test
>>> RSA verify test vector #1 (good): passed
>>> RSA verify test vector #2 (bad): passed
* Signuature Verification Test
>>> ECDSA: passed
>>> EC(DSA): passed
>>> EC_DH (no): passed
>>> RSA: passed
* Decryption Test
>>> RSA decrypt test vector #1: passed
>>> RSA decrypt test vector #2: passed
* RSA Alt Test: passed
* RSA Verification with option Test
>>> Verify ext RSA #2 (PKCS1 v2.1, salt_len = ANY, wrong message): passed
>>> Verify ext RSA #3 (PKCS1 v2.1, salt_len = 0, OK): passed
>>> Verify ext RSA #4 (PKCS1 v2.1, salt_len = max, OK): passed
>>> Verify ext RSA #5 (PKCS1 v2.1, wrong salt_len): passed
>>> Verify ext RSA #6 (PKCS1 v2.1, MGF1 alg != MSG hash alg): passed
>>> Verify ext RSA #7 (PKCS1 v2.1, wrong MGF1 alg != MSG hash alg): passed
>>> Verify ext RSA #8 (PKCS1 v2.1, RSASSA-PSS without options): passed
>>> Verify ext RSA #9 (PKCS1 v1.5, RSA with options): passed
>>> Verify ext RSA #10 (PKCS1 v1.5, RSA without options): passed
>>> Verify ext RSA #11 (PKCS1 v2.1, asking for ECDSA): passed
>>> Verify ext RSA #12 (PKCS1 v1.5, good): passed
* PK pair Test
>>> Check pair #1 (EC, OK): passed
>>> Check pair #2 (EC, bad): passed
```

Figure 106: Result of Crypto Public Key

15.1.12.1 Application Initialization

This example shows how to use the Public Key Abstraction Layer of the "mbedTLS" library.

```
void crypto_sample_pk(void *param)
{
    PRINTF("* PK Information\n");
    ret = crypto_sample_pk_utils(crypto_sample_pk_utils_list[i].type,
                                 crypto_sample_pk_utils_list[i].size,
                                 crypto_sample_pk_utils_list[i].len,
                                 crypto_sample_pk_utils_list[i].name);
```

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```
PRINTF("* RSA Verification Test\n");
ret = crypto_sample_pk_rsa_verify_test_vec(
          crypto_sample_pk_rsa_verify_test_vec_list[i].title,
          crypto_sample_pk_rsa_verify_test_vec_list[i].message_hex_string,
          crypto_sample_pk_rsa_verify_test_vec_list[i].digest,
          crypto_sample_pk_rsa_verify_test_vec_list[i].mod,
          crypto_sample_pk_rsa_verify_test_vec_list[i].radix_N,
          crypto_sample_pk_rsa_verify_test_vec_list[i].input_N,
          crypto_sample_pk_rsa_verify_test_vec_list[i].radix_E,
          crypto_sample_pk_rsa_verify_test_vec_list[i].input_E,
          crypto_sample_pk_rsa_verify_test_vec_list[i].result_hex_str,
          crypto_sample_pk_rsa_verify_test_vec_list[i].result);


PRINTF("* Signuature Verification Test\n");
ret = crypto_sample_pk_sign_verify(
         crypto_sample_pk_sign_verify_list[i].title,
         crypto_sample_pk_sign_verify_list[i].type,
         crypto_sample_pk_sign_verify_list[i].sign_ret,
         crypto_sample_pk_sign_verify_list[i].verify_ret);

PRINTF("* Decryption Test\n");
ret = crypto_sample_pk_rsa_decrypt_test_vec(
         crypto_sample_pk_rsa_decrypt_list[i].title,
         crypto_sample_pk_rsa_decrypt_list[i].cipher_hex,
         crypto_sample_pk_rsa_decrypt_list[i].mod,
         crypto_sample_pk_rsa_decrypt_list[i].radix_P,
         crypto_sample_pk_rsa_decrypt_list[i].input_P,
         crypto_sample_pk_rsa_decrypt_list[i].radix_Q,
         crypto_sample_pk_rsa_decrypt_list[i].input_Q,
         crypto_sample_pk_rsa_decrypt_list[i].radix_N,
         crypto_sample_pk_rsa_decrypt_list[i].input_N,
         crypto_sample_pk_rsa_decrypt_list[i].radix_E,
         crypto_sample_pk_rsa_decrypt_list[i].input_E,
         crypto_sample_pk_rsa_decrypt_list[i].clear_hex,
         crypto_sample_pk_rsa_decrypt_list[i].result);

ret = crypto_sample_pk_rsa_alt();

PRINTF("* RSA Verification with option Test\n");
ret = crypto_sample_pk_rsa_verify_ext_test_vec(
         crypto_sample_pk_rsa_verify_ext_list[i].title,
         crypto_sample_pk_rsa_verify_ext_list[i].message_hex_string,
         crypto_sample_pk_rsa_verify_ext_list[i].digest,
         crypto_sample_pk_rsa_verify_ext_list[i].mod,
         crypto_sample_pk_rsa_verify_ext_list[i].radix_N,
         crypto_sample_pk_rsa_verify_ext_list[i].input_N,
         crypto_sample_pk_rsa_verify_ext_list[i].radix_E,
         crypto_sample_pk_rsa_verify_ext_list[i].input_E,
         crypto_sample_pk_rsa_verify_ext_list[i].result_hex_str,
         crypto_sample_pk_rsa_verify_ext_list[i].pk_type,
         crypto_sample_pk_rsa_verify_ext_list[i].mgf1_hash_id,
         crypto_sample_pk_rsa_verify_ext_list[i].salt_len,
         crypto_sample_pk_rsa_verify_ext_list[i].result);

PRINTF("* PK pair Test\n");
ret = crypto_sample_pk_check_pair(
         crypto_sample_pk_check_pair_list[i].title,
         crypto_sample_pk_check_pair_list[i].pub_file,
         crypto_sample_pk_check_pair_list[i].prv_file,
```

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```
                crypto_sample_pk_check_pair_list[i].result);
}
```

15.1.12.2 How to Use Public Key Abstraction Layer

The "mbedTLS" library provides the Public Key Abstraction Layer for confidentiality, integrity, authentication, and non-repudiation based on asymmetric algorithms, using traditional RSA or Elliptic Curves.

The user needs to check which public key could be supported by the "mbedTLS" library. The example code below shows how to get and check public key information.

```
int crypto_sample_pk_utils(mbedtls_pk_type_t type, int size, int len, char *name)
{
    mbedtls_pk_context pk;

    // Initialize a mbedtls_pk_context.
    mbedtls_pk_init(&pk);

    /* Initialize a PK context with the information given
     * and allocates the type-specific PK subcontext.
     */
    ret = mbedtls_pk_setup(&pk, mbedtls_pk_info_from_type(type));

    // Get the key type.
    if (mbedtls_pk_get_type(&pk) != type) {
    }

    // Tell if a context can do the operation given by type.
    if (!mbedtls_pk_can_do(&pk, type)) {
    }

    // Get the size in bits of the underlying key.
    if (mbedtls_pk_get_bitlen(&pk) != (unsigned)size) {
    }

    // Get the length in bytes of the underlying key.
    if (mbedtls_pk_get_len(&pk) != (unsigned)len) {
    }

    // Access the type name.
    if ((ret = strcmp(mbedtls_pk_get_name(&pk), name)) != 0) {
    }

    // Free the components of a mbedtls_pk_context.
    mbedtls_pk_free(&pk);
}
```

The API details are as follows.

Table 48: APIs for Public Key Abstraction Layer

Item	Description
void mbedtls_pk_init(mbedtls_pk_context *ctx)	
Prototype	void mbedtls_pk_init(mbedtls_pk_context *ctx)
Parameter	ctx: The context to initialize. This must not be NULL.
Return	None.
Description	Initialize an mbedtls_pk_context (as NONE).

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Item	Description
int mbedtls_pk_setup(mbedtls_pk_context *ctx, const mbedtls_pk_info_t *info)	
Prototype	int mbedtls_pk_setup(mbedtls_pk_context *ctx, const mbedtls_pk_info_t *info)
Parameter	ctx: Context to initialize. It must not have been set up yet (type MBEDTLS_PK_NONE). info: Information to use.
Return	0 on success, MBEDTLS_ERR_PK_BAD_INPUT_DATA on invalid input, MBEDTLS_ERR_PK_ALLOC_FAILED on allocation failure.
Description	Initialize a PK context with the information given and allocate the type-specific PK subcontext.
mbedtls_pk_type_t mbedtls_pk_get_type(const mbedtls_pk_context *ctx)	
Prototype	mbedtls_pk_type_t mbedtls_pk_get_type(const mbedtls_pk_context *ctx)
Parameter	ctx: The PK context to use. It must have been initialized.
Return	MBEDTLS_PK_NONE for a context that has not been set up.
Description	Get the key type.
int mbedtls_pk_can_do(const mbedtls_pk_context *ctx, mbedtls_pk_type_t type)	
Prototype	int mbedtls_pk_can_do(const mbedtls_pk_context *ctx, mbedtls_pk_type_t type)
Parameter	ctx: The context to query. It must have been initialized. type: The desired type.
Return	1 if the context can do operations on the given type. 0 if the context cannot do the operations on the given type. This is always the case for a context that has been initialized but not set up, or that has been cleared with mbedtls_pk_free().
Description	Tell if a context can do the operation given by the type.
size_t mbedtls_pk_get_bitlen(const mbedtls_pk_context *ctx)	
Prototype	size_t mbedtls_pk_get_bitlen(const mbedtls_pk_context *ctx)
Parameter	ctx: The context to query. It must have been initialized.
Return	Key size in bits, or 0 on error.
Description	Get the size in bits of the underlying key.
static inline size_t mbedtls_pk_get_len(const mbedtls_pk_context *ctx)	
Prototype	static inline size_t mbedtls_pk_get_len(const mbedtls_pk_context *ctx)
Parameter	ctx: The context to query. It must have been initialized.
Return	Key size in bits, or 0 on error.
Description	Get the length in bytes of the underlying key.
const char* mbedtls_pk_get_name(const mbedtls_pk_context *ctx)	
Prototype	const char* mbedtls_pk_get_name(const mbedtls_pk_context *ctx)
Parameter	ctx: The PK context to use. It must have been initialized.
Return	Type name on success, or "invalid PK".
Description	Access the type name.
void mbedtls_pk_free(mbedtls_pk_context *ctx)	
Prototype	void mbedtls_pk_free(mbedtls_pk_context *ctx)
Parameter	ctx: The context to clear. It must have been initialized. If this is NULL, this function does nothing.

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Item	Description
Return	None.
Description	Free the components of a mbedtls_pk_context.

Function crypto_sample_pk_genkey describes how to generate a public key with the given algorithms (RSA or Elliptic curves).

```
int crypto_sample_pk_genkey(mbedtls_pk_context *pk)
{
    mbedtls_entropy_context *entropy = NULL;
    mbedtls_ctr_drbg_context *ctr_drbg = NULL;

    // Initialize the entropy context.
    mbedtls_entropy_init(entropy);

    // Initialize the CTR_DRBG context.
    mbedtls_ctr_drbg_init(ctr_drbg);

    // Seed and sets up the CTR_DRBG entropy source for future reseeds.
    mbedtls_ctr_drbg_seed(ctr_drbg, mbedtls_entropy_func, entropy, NULL, 0);

#if defined(MBEDTLS_RSA_C) && defined(MBEDTLS_GENPRIME)
    if (mbedtls_pk_get_type(pk) == MBEDTLS_PK_RSA) {
        // Generate the RSA key pair.
        ret = mbedtls_rsa_gen_key(mbedtls_pk_rsa(*pk),
                                  rnd_std_rand,
                                  ctr_drbg,
                                  RSA_KEY_SIZE, 3);
    }
#endif

#if defined(MBEDTLS_ECP_C)
    if ((mbedtls_pk_get_type(pk) == MBEDTLS_PK_ECKEY)
     || (mbedtls_pk_get_type(pk) == MBEDTLS_PK_ECKEY_DH)
     || (mbedtls_pk_get_type(pk) == MBEDTLS_PK_ECDSA)) {

        // Set a group using well-known domain parameters.
        ret = mbedtls_ecp_group_load(&mbedtls_pk_ec(*pk)->grp,
                                     MBEDTLS_ECP_DP_SECP192R1);

        // Generate key pair, wrapper for conventional base point
        ret = mbedtls_ecp_gen_keypair(&mbedtls_pk_ec(*pk)->grp,
                                      &mbedtls_pk_ec(*pk)->d,
                                      &mbedtls_pk_ec(*pk)->Q,
                                      rnd_std_rand, ctr_drbg);
    }
#endif
    mbedtls_ctr_drbg_free(ctr_drbg);
    mbedtls_entropy_free(entropy);
}
```

The API details are as follows.

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Table 49: APIs for Generating Key Pair

Item	Description
int mbedtls_rsa_gen_key(mbedtls_rsa_context *ctx, int (*f_rng)(void *, unsigned char *, size_t), void *p_rng, unsigned int nbits, int exponent)	
Prototype	int mbedtls_rsa_gen_key(mbedtls_rsa_context *ctx, int (*f_rng)(void *, unsigned char *, size_t), void *p_rng, unsigned int nbits, int exponent)
Parameter	ctx: The initialized RSA context used to hold the key. f_rng: The RNG function to be used for key generation. This must not be NULL. p_rng: The RNG context to be passed to f_rng. This may be NULL if f_rng does not need a context. nbits: The size of the public key in bits. exponent: The public exponent to use. For example, 65537. This must be odd and greater than 1.
Return	0 on success. An MBEDTLS_ERR_RSA_XXX error code on failure.
Description	This function generates an RSA keypair.
int mbedtls_ecp_gen_keypair(mbedtls_ecp_group *grp, mbedtls_mpi *d, mbedtls_ecp_point *Q, int (*f_rng)(void *, unsigned char *, size_t), void *p_rng)	
Prototype	int mbedtls_ecp_gen_keypair(mbedtls_ecp_group *grp, mbedtls_mpi *d, mbedtls_ecp_point *Q, int (*f_rng)(void *, unsigned char *, size_t), void *p_rng)
Parameter	grp: The ECP group to generate a key pair for. This must be initialized and have group parameters set, for example through mbedtls_ecp_group_load(). d: The destination MPI (secret part). This must be initialized. Q: The destination point (public part). This must be initialized. f_rng: The RNG function. This must not be NULL. p_rng: The RNG context to be passed to f_rng. This may be NULL if f_rng does not need a context argument.
Return	0 on success. An MBEDTLS_ERR_ECP_XXX or MBEDTLS_MPI_XXX error code on failure.
Description	This function generates an ECP keypair.

Function crypto_sample_pk_rsa_verify_test_vec describes how to verify RSA signatures with Public Key abstraction Layer functions.

```
int crypto_sample_pk_rsa_verify_test_vec(char *title, char *message_hex_string,
mbedtls_md_type_t digest, int mod, int radix_N, char *input_N, int radix_E, char
*input_E, char *result_hex_str, int result)
{
    mbedtls_rsa_context *rsa = NULL;
    mbedtls_pk_context pk;

    // Initialize a mbedtls_pk_context.
    mbedtls_pk_init(&pk);

    /* Initialize a PK context with the information given
     * and allocates the type-specific PK subcontext.
     */
    ret = mbedtls_pk_setup(&pk, mbedtls_pk_info_from_type(MBEDTLS_PK_RSA));

    // Quick access to an RSA context inside a PK context.
    rsa = mbedtls_pk_rsa(pk);

    rsa->len = mod / 8;
```

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```
    MBEDTLS_MPI_CHK(mbedtls_mpi_read_string(&rsa->N, radix_N, input_N));
    MBEDTLS_MPI_CHK(mbedtls_mpi_read_string(&rsa->E, radix_E, input_E));

    msg_len = unhexify(message_str, message_hex_string);

    unhexify(result_str, result_hex_str);

    // Get the message-digest information associated with the given digest type.
    if (mbedtls_md_info_from_type(digest) != NULL) {

        /* Calculates the message-digest of a buffer,
         * with respect to a configurable message-digest algorithm in a single call.
         */
        ret = mbedtls_md(mbedtls_md_info_from_type(digest),
                         message_str, msg_len,
                         hash_result);
    }

    // Verify signature (including padding if relevant) & Check result with
    // expected result.
    ret = mbedtls_pk_verify(&pk, digest, hash_result, 0, result_str,
                            mbedtls_pk_get_len(&pk));

    // Free the components of a mbedtls_pk_context.
    mbedtls_pk_free(&pk);
}
```

The API details are as follows.

Table 50: APIs for Verify Signature

Item	Description
int mbedtls_pk_verify(mbedtls_pk_context *ctx, mbedtls_md_type_t md_alg, const unsigned char *hash, size_t hash_len, const unsigned char *sig, size_t sig_len)	
Prototype	int mbedtls_pk_verify(mbedtls_pk_context *ctx, mbedtls_md_type_t md_alg, const unsigned char *hash, size_t hash_len, const unsigned char *sig, size_t sig_len)
Parameter	ctx: The PK context to use. It must have been set up. md_alg: Hash algorithm used. hash: Hash of the message to sign. hash_len: Hash length or 0. sig: Signature to verify. sig_len: Signature length.
Return	0 on success (signature is valid), MBEDTLS_ERR_PK_SIG_LEN_MISMATCH if there is a valid signature in sig but its length is less than siglen, or a specific error code.
Description	Verify signature (including padding if relevant).

Function crypto_sample_pk_sign_verify describes how to generate a key, make a signature, and verify this with the given cryptographic algorithms.

```
int crypto_sample_pk_sign_verify(char *title, mbedtls_pk_type_t type, int sign_ret,
int verify_ret)
{
    mbedtls_pk_context pk;

    // Initialize a mbedtls_pk_context.
    mbedtls_pk_init(&pk);
```

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```
    /* Initialize a PK context with the information given
     * and allocates the type-specific PK subcontext.
     */
    ret = mbedtls_pk_setup(&pk, mbedtls_pk_info_from_type(type));

    // Generate key pair by the type.
    ret = crypto_sample_pk_genkey(&pk);

    // Make signature, including padding if relevant and Check result with expected
    // result.
    ret = mbedtls_pk_sign(&pk, MBEDTLS_MD_SHA256,
                          hash, 64, sig, &sig_len,
                          rnd_std_rand, NULL);

    // Verify signature (including padding if relevant) and Check result with
    // expected result.
    ret = mbedtls_pk_verify(&pk, MBEDTLS_MD_SHA256, hash, 64, sig, sig_len);

    // Free the components of a mbedtls_pk_context.
    mbedtls_pk_free(&pk);
}
```

The API details are as follows.

Table 51: APIs for Make Signature

Item	Description
int mbedtls_pk_sign(mbedtls_pk_context *ctx, mbedtls_md_type_t md_alg, const unsigned char *hash, size_t hash_len, unsigned char *sig, size_t *sig_len, int (*f_rng)(void *, unsigned char *, size_t), void *p_rng)	
Prototype	int mbedtls_pk_sign(mbedtls_pk_context *ctx, mbedtls_md_type_t md_alg, const unsigned char *hash, size_t hash_len, unsigned char *sig, size_t *sig_len, int (*f_rng)(void *, unsigned char *, size_t), void *p_rng)
Parameter	ctx: The PK context to use. Must have been set up with a private key. md_alg: Hash algorithm used (see notes). hash: Hash of the message to sign. hash_len: Hash length or 0 (see notes). sig: Place to write the signature. sig_len: Number of bytes written. f_rng: RNG function. p_rng: RNG parameter.
Return	0 on success, or a specific error code.
Description	Make signature, including padding if relevant.

Function crypto_sample_pk_rsa_decrypt_test_vec describes how RSA is decrypted using Public Key Abstraction Layer's functions. Encryption could also be used. But this example only explains RSA decryption.

```
int crypto_sample_pk_rsa_decrypt_test_vec(char *title, char *cipher_hex, int mod,
int radix_P, char *input_P, int radix_Q, char *input_Q, int radix_N, char *input_N,
int radix_E, char *input_E, char *clear_hex, int result)
{
    rnd_pseudo_info *rnd_info = NULL;
    mbedtls_rsa_context *rsa = NULL;
    mbedtls_pk_context pk;

    // Initialize a mbedtls_pk_context.
```

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```
    mbedtls_pk_init(&pk);

    /* Initialize a PK context with the information given
     * and allocates the type-specific PK subcontext.
     */
    ret = mbedtls_pk_setup(&pk, mbedtls_pk_info_from_type(MBEDTLS_PK_RSA));

    // Quick access to an RSA context inside a PK context.
    rsa = mbedtls_pk_rsa(pk);

    // Import a set of core parameters into an RSA context.
    ret = mbedtls_rsa_import(rsa, &N, &P, &Q, NULL, &E);

    // Retrieve the length of RSA modulus in Bytes.
    if (mbedtls_rsa_get_len(rsa) != (size_t)(mod / 8)) {
    }

    // Complete an RSA context from a set of imported core parameters.
    ret = mbedtls_rsa_complete(rsa);

    // Decrypt message (including padding if relevant).
    ret = mbedtls_pk_decrypt(&pk, cipher, cipher_len,
                             output, &olen, (1000 * sizeof(unsigned char)),
                             rnd_pseudo_rand, rnd_info);

    // Free the components of a mbedtls_pk_context.
    mbedtls_pk_free(&pk);
}
```

The API details are as follows.

Table 52:APIs for PKCS#11 RSA

Item	Description
int mbedtls_rsa_import(mbedtls_rsa_context *ctx, const mbedtls_mpi *N, const mbedtls_mpi *P, const mbedtls_mpi *Q, const mbedtls_mpi *D, const mbedtls_mpi *E)	
Prototype	int mbedtls_rsa_import(mbedtls_rsa_context *ctx, const mbedtls_mpi *N, const mbedtls_mpi *P, const mbedtls_mpi *Q, const mbedtls_mpi *D, const mbedtls_mpi *E)
Parameter	ctx: The initialized RSA context to store the parameters in. N: The RSA modulus. This may be NULL. P: The first prime factor of N. This may be NULL. Q: The second prime factor of N. This may be NULL. D: The private exponent. This may be NULL. E: The public exponent. This may be NULL.
Return	0 on success. A non-zero error code on failure.
Description	This function imports a set of core parameters into an RSA context.
int mbedtls_rsa_complete(mbedtls_rsa_context *ctx)	
Prototype	int mbedtls_rsa_complete(mbedtls_rsa_context *ctx)
Parameter	ctx: The initialized RSA context holding imported parameters.
Return	0 on success. MBEDTLS_ERR_RSA_BAD_INPUT_DATA if the attempted derivations failed.

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Item	Description
Description	This function completes an RSA context from a set of imported core parameters. To set up an RSA public key, precisely N and E must have been imported. To set up an RSA private key, sufficient information must be present for the other parameters to be derivable. The default implementation supports the following: > Derive P, Q from N, D, E. > Derive N, D from P, Q, E. Alternative implementations need not support these. If this function runs successfully, it guarantees that the RSA context can be used for RSA operations without the risk of failure or crash.
int mbedtls_pk_decrypt(mbedtls_pk_context *ctx, const unsigned char *input, size_t ilen, unsigned char *output, size_t *olen, size_t osize, int (*f_rng)(void *, unsigned char *, size_t), void *p_rng)	
Prototype	int mbedtls_pk_decrypt(mbedtls_pk_context *ctx, const unsigned char *input, size_t ilen, unsigned char *output, size_t *olen, size_t osize, int (*f_rng)(void *, unsigned char *, size_t), void *p_rng)
Parameter	ctx: The PK context to use. It must have been set up with a private key. input: Input to decrypt. ilen: Input size. output: Decrypted output. olen: Decrypted message length. osize: Size of the output buffer. f_rng: RNG function. p_rng: RNG parameter.
Return	0 on success, or a specific error code.
Description	Decrypt message (including padding if relevant).

Function crypto_sample_pk_rsa_alt describes how RSA ALT context creates and decrypts a signature.

```
int crypto_sample_pk_rsa_alt()
{
    /*
     * An rsa_alt context can only do private operations (decrypt, sign).
     * Test it against the public operations (encrypt, verify) of a
     * corresponding rsa context.
     */

    mbedtls_rsa_context *raw = NULL;
    mbedtls_pk_context rsa, alt;
    mbedtls_pk_debug_item *dbg_items = NULL;

    // Initialize an RSA context.
    mbedtls_rsa_init(raw, MBEDTLS_RSA_PKCS_V15, MBEDTLS_MD_NONE);

    // Initialize a mbedtls_pk_context.
    mbedtls_pk_init(&rsa);
    mbedtls_pk_init(&alt);

    /* Initialize a PK context with the information given
     * and allocates the type-specific PK subcontext.
     */
    ret = mbedtls_pk_setup(&rsa, mbedtls_pk_info_from_type(MBEDTLS_PK_RSA));
```

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```
    // Generate key pair by the type.
    ret = crypto_sample_pk_genkey(&rsa);

    // Copy the components of an RSA context.
    ret = mbedtls_rsa_copy(raw, mbedtls_pk_rsa(rsa));

    // Initialize PK RSA_ALT context
    ret = mbedtls_pk_setup_rsa_alt(&alt, (void *)raw,
                                   crypto_sample_rsa_decrypt_func,
                                   crypto_sample_rsa_sign_func,
                                   crypto_sample_rsa_key_len_func);

    // Encrypt message (including padding if relevant).
    ret = mbedtls_pk_encrypt(&rsa, msg, 50, cipher,
                             &cipher_len, 1000, rnd_std_rand, NULL);

    // Decrypt message (including padding if relevant).
    ret = mbedtls_pk_decrypt(&alt, cipher, cipher_len,
                              test, &test_len, 1000, rnd_std_rand, NULL);

    // Free the components of an RSA key.
    mbedtls_rsa_free(raw);

    // Free the components of a mbedtls_pk_context.
    mbedtls_pk_free(&rsa);
    mbedtls_pk_free(&alt);
}
```

The API details are as follows.

Table 53: APIs for Initialize RSA

Item	Description
int mbedtls_pk_setup_rsa_alt(mbedtls_pk_context *ctx, void * key, mbedtls_pk_rsa_alt_decrypt_func decrypt_func, mbedtls_pk_rsa_alt_sign_func sign_func, mbedtls_pk_rsa_alt_key_len_func key_len_func)	
Prototype	int mbedtls_pk_setup_rsa_alt(mbedtls_pk_context *ctx, void * key, mbedtls_pk_rsa_alt_decrypt_func decrypt_func, mbedtls_pk_rsa_alt_sign_func sign_func, mbedtls_pk_rsa_alt_key_len_func key_len_func)
Parameter	ctx: Context to initialize. It must not have been set up yet (type MBEDTLS_PK_NONE). key: RSA key pointer. decrypt_func: Decryption function. sign_func: Signing function. key_len_func: Function returning key length in bytes.
Return	0 on success, or MBEDTLS_ERR_PK_BAD_INPUT_DATA if the context was not already initialized as RSA_ALT.
Description	Initialize an RSA-alt context.

The code example shows how to check if a public and private pair of keys matches.

```
int crypto_sample_pk_check_pair(char *title, char *pub_file, char *prv_file, int
result)
{
    mbedtls_pk_context pub, prv, alt;

    // Initialize a mbedtls_pk_context.
    mbedtls_pk_init(&pub);
```

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```
    mbedtls_pk_init(&prv);

    // Parse a public key in PEM or DER format.
    ret = mbedtls_pk_parse_public_key(&pub,
                                      (const unsigned char *)pub_file,
                                      (strlen(pub_file) + 1));

    // Parse a private key in PEM or DER format.
    ret = mbedtls_pk_parse_key(&prv,
                               (const unsigned char *)prv_file,
                               (strlen(prv_file) + 1), NULL, 0);

    // Check if a public-private pair of keys matches.
    ret = mbedtls_pk_check_pair(&pub, &prv);

    mbedtls_pk_free(&pub);
    mbedtls_pk_free(&prv);
}
```

The API details are as follows.

Table 54: APIs for Parse Private and Public Key

Item	Description
int mbedtls_pk_parse_public_key(mbedtls_pk_context *ctx, const unsigned char *key, size_t keylen)	
Prototype	int mbedtls_pk_parse_public_key(mbedtls_pk_context *ctx, const unsigned char *key, size_t keylen)
Parameter	ctx: The PK context to fill. It must have been initialized but not set up. key: Input buffer to parse. The buffer must contain the input exactly, with no extra trailing material. For PEM, the buffer must contain a null-terminated string. keylen: Size of key in bytes. For PEM data, this includes the terminating null byte, so keylen must be equal to strlen(key) + 1.
Return	0 if successful, or a specific PK or PEM error code
Description	Parse a public key in PEM or DER format.
int mbedtls_pk_parse_key(mbedtls_pk_context *pk, const unsigned char *key, size_t keylen, const unsigned char *pwd, size_t pwdlen)	
Prototype	int mbedtls_pk_parse_key(mbedtls_pk_context *pk, const unsigned char *key, size_t keylen, const unsigned char *pwd, size_t pwdlen)
Parameter	pk: The PK context to fill. It must have been initialized but not set up. key: Input buffer to parse. The buffer must contain the input exactly, with no extra trailing material. For PEM, the buffer must contain a null-terminated string. keylen: Size of key in bytes. For PEM data, this includes the terminating null byte, so keylen must be equal to strlen(key) + 1. pwd: Optional password for decryption. Pass NULL if expecting a non-encrypted key. Pass a string of pwdlen bytes if expecting an encrypted key; a non-encrypted key will also be accepted. The empty password is not supported. pwdlen: Size of the password in bytes. Ignored if pwd is NULL.
Return	0 if successful, or a specific PK or PEM error code
Description	Parse a private key in PEM or DER format.
int mbedtls_pk_check_pair(const mbedtls_pk_context *pub, const mbedtls_pk_context *prv)	
Prototype	int mbedtls_pk_check_pair(const mbedtls_pk_context *pub, const mbedtls_pk_context *prv)
Parameter	pub: Context holding a public key. prv: Context holding a private (and public) key.

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Item	Description
Return	0 on success or MBEDTLS_ERR_PK_BAD_INPUT_DATA
Description	Check if a public-private pair of keys matches.

15.1.13 Cryptographic Algorithms – Generic Cipher Wrapper

The Generic cipher wrapper sample application demonstrates common use cases of a generic cipher wrapper API of the "mbedTLS" library that is included in the DA16200 SDK.

```
* AES-128-ECB(enc, dec): passed
* AES-192-ECB(enc, dec): passed
* AES-256-ECB(enc, dec): passed
* AES-128-CBC(enc, dec): passed
* AES-192-CBC(enc, dec): passed
* AES-256-CBC(enc, dec): passed
* AES-128-CFB128(enc, dec): passed
* AES-192-CFB128(enc, dec): passed
* AES-256-CFB128(enc, dec): passed
* AES-128-CTR(enc, dec): passed
* AES-192-CTR(enc, dec): passed
* AES-256-CTR(enc, dec): passed
* AES-128-GCM(enc, dec): passed
* AES-192-GCM(enc, dec): passed
* AES-256-GCM(enc, dec): passed
* DES-CBC(enc, dec): passed
* DES-EDE-CBC(enc, dec): passed
* DES-EDE3-CBC(enc, dec): passed
* AES-128-CCM(enc, dec): passed
* AES-192-CCM(enc, dec): passed
* AES-256-CCM(enc, dec): passed
```

Figure 107: Result of Generic Cipher

15.1.13.1 Application Initialization

The generic cipher wrapper contains an abstraction interface for use with the cipher primitives that the library provides. It provides a common interface to all the available cipher operations.

```
void crypto_sample_cipher(void *param)
{
      crypto_sample_cipher_wrapper();

      vTaskDelete(NULL);

      return ;
}
```

15.1.13.2 How Generic Cipher Wrapper is Used

This example describes how to encrypt and decrypt with generic cipher wrapper functions.

```
int crypto_sample_cipher_wrapper()
{
    mbedtls_cipher_type_t cipher_type = MBEDTLS_CIPHER_NONE;
    mbedtls_cipher_context_t cipher_ctx;
    mbedtls_cipher_info_t *cipherinfo = NULL;
    mbedtls_cipher_mode_t cipher_mode = MBEDTLS_MODE_NONE;

    for (cipher_type = MBEDTLS_CIPHER_AES_128_ECB ;
         cipher_type <= MBEDTLS_CIPHER_CAMELLIA_256_CCM ;
         cipher_type++) {

        flag_pass = FALSE;
```

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```
// Initialize a cipher_context as NONE.
mbedtls_cipher_init(cipher_ctx);

// Retrieve the cipher-information structure associated with the given
// cipher type.
cipherinfo = (mbedtls_cipher_info_t *)mbedtls_cipher_info_from_type
             (cipher_type);

// Initialize and fill the cipher-context structure with the appropriate
// values.
mbedtls_cipher_setup(&cipher_ctx, cipherinfo);

// Return the key length of the cipher.
cipher_keylen = mbedtls_cipher_get_key_bitlen(&cipher_ctx);

// Return the mode of operation for the cipher.
cipher_mode = mbedtls_cipher_get_cipher_mode(&cipher_ctx);

// Return the size of the IV or nonce of the cipher, in Bytes.
cipher_ivlen = mbedtls_cipher_get_iv_size(&cipher_ctx);

// Return the block size of the given cipher.
cipher_blksiz = mbedtls_cipher_get_block_size(&cipher_ctx);

// Return the name of the given cipher as a string.
cipher_name = (char *)mbedtls_cipher_get_name(&cipher_ctx);

PRINTF("* %s", cipher_name);

PRINTF("(enc, ");

if (cipher_adlen == 0) { // No CCM or GCM
    // Set the key to use with the given context.
    cipher_status = mbedtls_cipher_setkey(&cipher_ctx,
                                          cipher_key, cipher_keylen,
                                          MBEDTLS_ENCRYPT);

    // Set the initialization vector (IV) or nonce.
    cipher_status = mbedtls_cipher_set_iv(&cipher_ctx,
                                          cipher_iv, cipher_ivlen);

    // Reset the cipher state.
    cipher_status = mbedtls_cipher_reset(&cipher_ctx);

    // Encrypt or decrypt using the given cipher context.
    cipher_status = mbedtls_cipher_update(&cipher_ctx,
                                          plain_in, plain_inlen,
                                          ciphertext, &ciphertext_len);

    // Finish the operation.
    cipher_status = mbedtls_cipher_finish(&cipher_ctx,
                                         &(ciphertext[ciphertext_len]),
                                         &ciphertext_finlen);

} else {
    // Set the key to use with the given context.
    cipher_status = mbedtls_cipher_setkey(&cipher_ctx,
                                          cipher_key, cipher_keylen,
                                          MBEDTLS_ENCRYPT);
```

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```
            // Perform autenticated encryption (AEAD).
            cipher_status = mbedtls_cipher_auth_encrypt(&cipher_ctx,
                                                        cipher_iv, cipher_ivlen,
                                                        cipher_ad, cipher_adlen,
                                                        plain_in, plain_inlen,
                                                        ciphertext, &ciphertext_len,
                                                        cipher_tag, cipher_taglen);
        }

        PRINTF("dec): ");

        if (cipher_adlen == 0) { // No CCM or GCM
            // Set the key to use with the given context.
            cipher_status = mbedtls_cipher_setkey(&cipher_ctx,
                                                  cipher_key, cipher_keylen,
                                                  MBEDTLS_DECRYPT);

            // Set the initialization vector (IV) or nonce.
            cipher_status = mbedtls_cipher_set_iv(&cipher_ctx,
                                                  cipher_iv, cipher_ivlen);
            // Reset the cipher state.
            cipher_status = mbedtls_cipher_reset(&cipher_ctx);

            // Encrypt or decrypt using the given cipher context.
            cipher_status = mbedtls_cipher_update(&cipher_ctx,
                                  ciphertext, (ciphertext_len + ciphertext_finlen),
                                  plain_out, &plain_outlen);

            // Finish the operation.
            cipher_status = mbedtls_cipher_finish(&cipher_ctx,
                                                  &(plain_out[plain_outlen]),
                                                  &plain_finlen);
        } else {
            // Set the key to use with the given context.
            cipher_status = mbedtls_cipher_setkey(&cipher_ctx,
                                                  cipher_key, cipher_keylen,
                                                  MBEDTLS_DECRYPT);

            // Perform autenticated decryption (AEAD).
            cipher_status = mbedtls_cipher_auth_decrypt(&cipher_ctx,
                                                        cipher_iv, cipher_ivlen,
                                                        cipher_ad, cipher_adlen,
                                                        ciphertext, ciphertext_len,
                                                        plain_out, &plain_outlen,
                                                        cipher_tag, cipher_taglen);
        }

        // Free and clear the cipher-specific context of ctx.
        mbedtls_cipher_free(&cipher_ctx);
    }
}
```

The API details are as follows.

Table 55: APIs for Generic Cipher Wrapper

Item	Description
void mbedtls_cipher_init(mbedtls_cipher_context_t *ctx)	
Prototype	void mbedtls_cipher_init(mbedtls_cipher_context_t *ctx)

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Item	Description
Parameter	ctx: The context to be initialized. This must not be NULL.
Return	None.
Description	This function initializes a cipher_context as NONE.
void mbedtls_cipher_free(mbedtls_cipher_context_t *ctx)	
Prototype	void mbedtls_cipher_free(mbedtls_cipher_context_t *ctx)
Parameter	ctx: The context to be freed. If this is NULL, the function has no effect, otherwise this must point to an initialized context.
Return	None.
Description	This function frees and clears the cipher-specific context of ctx. Freeing ctx itself remains the responsibility of the caller.
const mbedtls_cipher_info_t* mbedtls_cipher_info_from_type(const mbedtls_cipher_type_t cipher_type)	
Prototype	Const mbedtls_cipher_info_t* mbedtls_cipher_info_from_type(const mbedtls_cipher_type_t cipher_type)
Parameter	cipher_type: Type of the cipher to search for.
Return	The cipher information structure associated with the given cipher_type. NULL if the associated cipher information is not found.
Description	This function retrieves the cipher-information structure associated with the given cipher type.
int mbedtls_cipher_setup(mbedtls_cipher_context_t *ctx, const mbedtls_cipher_info_t *cipher_info)	
Prototype	int mbedtls_cipher_setup(mbedtls_cipher_context_t *ctx, const mbedtls_cipher_info_t *cipher_info)
Parameter	ctx: The context to initialize. This must be initialized. cipher_info: The cipher to use.
Return	0 on success. MBEDTLS_ERR_CIPHER_BAD_INPUT_DATA on parameter-verification failure. MBEDTLS_ERR_CIPHER_ALLOC_FAILED if allocation of the cipher-specific context fails.
Description	This function initializes and fills the cipher-context structure with the appropriate values. It also clears the structure.
static inline int mbedtls_cipher_get_key_bitlen(const mbedtls_cipher_context_t *ctx)	
Prototype	static inline int mbedtls_cipher_get_key_bitlen(const mbedtls_cipher_context_t *ctx)
Parameter	ctx: The context of the cipher. This must be initialized.
Return	The key length of the cipher in bits. MBEDTLS_KEY_LENGTH_NONE if ctx has not been initialized.
Description	This function returns the key length of the cipher.
static inline mbedtls_cipher_mode_t mbedtls_cipher_get_cipher_mode(const mbedtls_cipher_context_t *ctx)	
Prototype	static inline mbedtls_cipher_mode_t mbedtls_cipher_get_cipher_mode(const mbedtls_cipher_context_t *ctx)
Parameter	ctx: The context of the cipher. This must be initialized.
Return	The mode of operation. MBEDTLS_MODE_NONE if ctx has not been initialized.
Description	This function returns the mode of operation for the cipher.

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Item	Description
static inline int mbedtls_cipher_get_iv_size(const mbedtls_cipher_context_t *ctx)	
Prototype	static inline int mbedtls_cipher_get_iv_size(const mbedtls_cipher_context_t *ctx)
Parameter	ctx: The context of the cipher. This must be initialized.
Return	The recommended IV size if no IV has been set. 0 for ciphers not using an IV or a nonce. The actual size if an IV has been set.
Description	This function returns the size of the IV or nonce of the cipher, in Bytes.
static inline unsigned int mbedtls_cipher_get_block_size(const mbedtls_cipher_context_t *ctx)	
Prototype	static inline unsigned int mbedtls_cipher_get_block_size(const mbedtls_cipher_context_t *ctx)
Parameter	ctx: The context of the cipher. This must be initialized.
Return	The block size of the underlying cipher. 0 if ctx has not been initialized.
Description	This function returns the block size of the given cipher.
static inline const char *mbedtls_cipher_get_name(const mbedtls_cipher_context_t *ctx)	
Prototype	static inline const char *mbedtls_cipher_get_name(const mbedtls_cipher_context_t *ctx)
Parameter	ctx: The context of the cipher. This must be initialized.
Return	The name of the cipher. NULL if ctx is not initialized.
Description	This function returns the name of the given cipher as a string.
int mbedtls_cipher_setkey(mbedtls_cipher_context_t *ctx, const unsigned char *key, int key_bitlen, const mbedtls_operation_t operation)	
Prototype	int mbedtls_cipher_setkey(mbedtls_cipher_context_t *ctx, const unsigned char *key, int key_bitlen, const mbedtls_operation_t operation)
Parameter	ctx: The generic cipher context. This must be initialized and bound to a cipher information structure. key: The key to use. This must be a readable buffer of at least key_bitlen Bits. key_bitlen: The key length to use, in Bits. operation: The operation that the key will be used for: MBEDTLS_ENCRYPT or MBEDTLS_DECRYPT.
Return	0 on success. MBEDTLS_ERR_CIPHER_BAD_INPUT_DATA on parameter-verification failure. A cipher-specific error code on failure.
Description	This function sets the key to use with the given context.
int mbedtls_cipher_set_iv(mbedtls_cipher_context_t *ctx, const unsigned char *iv, size_t iv_len)	
Prototype	int mbedtls_cipher_set_iv(mbedtls_cipher_context_t *ctx, const unsigned char *iv, size_t iv_len)
Parameter	ctx: The generic cipher context. This must be initialized and bound to a cipher information structure. iv: The IV to use, or NONCE_COUNTER for CTR-mode ciphers. This must be a readable buffer of at least iv_len Bytes. iv_len: The IV length for ciphers with variable-size IV. This parameter is discarded by ciphers with fixed-size IV.
Return	0 on success. MBEDTLS_ERR_CIPHER_BAD_INPUT_DATA on parameter-verification failure.

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Item	Description
Description	This function sets the initialization vector (IV) or nonce.
int mbedtls_cipher_reset(mbedtls_cipher_context_t *ctx)	
Prototype	int mbedtls_cipher_reset(mbedtls_cipher_context_t *ctx)
Parameter	ctx: The generic cipher context. This must be initialized.
Return	0 on success. MBEDTLS_ERR_CIPHER_BAD_INPUT_DATA on parameter-verification failure.
Description	This function resets the cipher state.
int mbedtls_cipher_update(mbedtls_cipher_context_t *ctx, const unsigned char *input, size_t ilen, unsigned char *output, size_t *olen)	
Prototype	int mbedtls_cipher_update(mbedtls_cipher_context_t *ctx, const unsigned char *input, size_t ilen, unsigned char *output, size_t *olen)
Parameter	ctx: The generic cipher context. This must be initialized and bound to a key. input: The buffer holding the input data. This must be a readable buffer of at least ilen Bytes. ilen: The length of the input data. output: The buffer for the output data. This must be able to hold at least ilen + block_size. This must not be the same buffer as input. olen: The length of the output data, to be updated with the actual number of Bytes written. This must not be NULL.
Return	0 on success. MBEDTLS_ERR_CIPHER_BAD_INPUT_DATA on parameter-verification failure. MBEDTLS_ERR_CIPHER_FEATURE_UNAVAILABLE on an unsupported mode for a cipher. A cipher-specific error code on failure.
Description	The generic cipher update function. It encrypts or decrypts using the given cipher context. Writes as many block-sized blocks of data as possible to output. Any data that cannot be written immediately is either added to the next block or flushed when mbedtls_cipher_finish() is called. Exception: For MBEDTLS_MODE_ECB, expects a single block in size. For example, 16 Bytes for AES.
int mbedtls_cipher_finish(mbedtls_cipher_context_t *ctx, unsigned char *output, size_t *olen)	
Prototype	int mbedtls_cipher_finish(mbedtls_cipher_context_t *ctx, unsigned char *output, size_t *olen)
Parameter	ctx: The generic cipher context. This must be initialized and bound to a key. output: The buffer to write data to. This needs to be a writable buffer of at least block_size Bytes. olen: The length of the data written to the output buffer. This may not be NULL.
Return	0 on success. MBEDTLS_ERR_CIPHER_BAD_INPUT_DATA on parameter-verification failure. MBEDTLS_ERR_CIPHER_FULL_BLOCK_EXPECTED on decryption expecting a full block but not receiving one. MBEDTLS_ERR_CIPHER_INVALID_PADDING on invalid padding while decrypting. A cipher-specific error code on failure.
Description	The generic cipher finalization function. If data still needs to be flushed from an incomplete block, the data contained in it is padded to the size of the last block and written to the output buffer.

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Item	Description
int mbedtls_cipher_auth_encrypt(mbedtls_cipher_context_t *ctx, const unsigned char *iv, size_t iv_len, const unsigned char *ad, size_t ad_len, const unsigned char *input, size_t ilen, unsigned char *output, size_t *olen, unsigned char *tag, size_t tag_len)	
Prototype	int mbedtls_cipher_auth_encrypt(mbedtls_cipher_context_t *ctx, const unsigned char *iv, size_t iv_len, const unsigned char *ad, size_t ad_len, const unsigned char *input, size_t ilen, unsigned char *output, size_t *olen, unsigned char *tag, size_t tag_len)
Parameter	ctx: The generic cipher context. This must be initialized and bound to a key. iv: The IV to use, or NONCE_COUNTER for CTR-mode ciphers. This must be a readable buffer of at least iv_len Bytes. iv_len: The IV length for ciphers with variable-size IV. This parameter is discarded by ciphers with fixed-size IV. ad: The additional data to authenticate. This must be a readable buffer of at least ad_len Bytes. ad_len: The length of ad. input: The buffer holding the input data. This must be a readable buffer of at least ilen Bytes. ilen: The length of the input data. output: The buffer for the output data. This must be able to hold at least ilen Bytes. olen: The length of the output data, to be updated with the actual number of Bytes written. This must not be NULL. tag: The buffer for the authentication tag. This must be a writable buffer of at least tag_len Bytes. tag_len: The desired length of the authentication tag.
Return	0 on success. MBEDTLS_ERR_CIPHER_BAD_INPUT_DATA on parameter-verification failure. A cipher-specific error code on failure.
Description	The generic authenticated encryption (AEAD) function.
int mbedtls_cipher_auth_decrypt(mbedtls_cipher_context_t *ctx, const unsigned char *iv, size_t iv_len, const unsigned char *ad, size_t ad_len, const unsigned char *input, size_t ilen, unsigned char *output, size_t *olen, const unsigned char *tag, size_t tag_len)	
Prototype	int mbedtls_cipher_auth_decrypt(mbedtls_cipher_context_t *ctx, const unsigned char *iv, size_t iv_len, const unsigned char *ad, size_t ad_len, const unsigned char *input, size_t ilen, unsigned char *output, size_t *olen, const unsigned char *tag, size_t tag_len)
Parameter	ctx: The generic cipher context. This must be initialized and bound to a key. iv: The IV to use, or NONCE_COUNTER for CTR-mode ciphers. This must be a readable buffer of at least iv_len Bytes. iv_len: The IV length for ciphers with variable-size IV. This parameter is discarded by ciphers with fixed-size IV. ad: The additional data to be authenticated. This must be a readable buffer of at least ad_len Bytes. ad_len: The length of ad. input: The buffer holding the input data. This must be a readable buffer of at least ilen Bytes. ilen: The length of the input data. output: The buffer for the output data. This must be able to hold at least ilen Bytes. olen: The length of the output data, to be updated with the actual number of Bytes written. This must not be NULL. tag: The buffer holding the authentication tag. This must be a readable buffer of at least tag_len Bytes. tag_len: The length of the authentication tag.

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Item	Description
Return	0 on success. MBEDTLS_ERR_CIPHER_BAD_INPUT_DATA on parameter-verification failure. MBEDTLS_ERR_CIPHER_AUTH_FAILED if data is not authentic. A cipher-specific error code on failure.
Description	The generic authenticated decryption (AEAD) function.

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16 Peripheral Examples

16.1 UART

Along with a UART0 interface for the debug console, the DA16200 SDK has a UART1 or UART2 interface to communicate with an external MCU. GPIOA[4] and GPIOA[5] can be used to this interface.

16.1.1 Introduction

The DA16200/DA16600 has two UARTs (Universal Asynchronous Receiver-Transmitter), which have the following features:

- Programmable use of UART
- Compliance to the AMBA AHB bus specification for easy integration into SoC implementation
- Support both byte and word access for reduction of bus burden
- Support both RS-232 and RS-485
- Separate 32x8 bit transmit and 32x12 bit receive FIFO memory buffers to reduce CPU interrupts
- Programmable FIFO disabling for 1-byte depth
- Programmable baud rate generator
- Standard asynchronous communication bits (start, stop and parity). These are added before transmission and removed upon reception
- Independent masking of transmit FIFO, receive FIFO, receive timeout
- Support for Direct Memory Access (DMA)
- False start bit detection
- Programmable flow control
- Fully programmable serial interface characteristics:
  - Data can be 5, 6, 7 or 8 bits
  - Even, odd, stick or no-parity bit generation and detection
  - 1 or 2 stop bit generation
  - Baud rate generation

Table 56: UART Pin Configuration

Pin Name	Pin Number		I/O	Function Name
	QFN	fcCSP		
UART0_RXD	12	M10	I	UART0_RXD
UART0_TXD	11	L9	O	UART0_TXD
GPIOA7	31	E1	I	UART1_RXD
GPIOA5	33	D2	I	
GPIOA3	36	D4	I	
GPIOA1	38	C3	I	
GPIOA6	32	E3	O	UART1_TXD
GPIOA4	34	F4	O	
GPIOA2	37	B2	O	
GPIOA0	39	A3	O	
GPIOA5	33	D2	I	UART1_CTS
GPIOA4	34	F4	O	UART1_RTS

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Pin Name	Pin Number		I/O	Function Name
	QFN	fcCSP		
GPIOA11	27	G1	I	UART2_RXD
GPIOC7	9	K12	I	
F_IO2	16	J7	I	
GPIOA10	28	F2	O	UART2_TXD
GPIOC6	10	L11	O	
F_IO3	17	K6	O	

16.1.2 API

Table 57: APIs for UART Interface

Item		Description
HANDLE UART_CREATE(UART_UNIT_IDX dev_idx)		
Parameter	dev_idx	Device index
Return		If succeeded, return handle for such device. If failed, return NULL.

Description		Function to create a handle with parameter dev_idx designated.
		The DA16200/DA16600 has two UART ports.
		`typedef enum __uart_unit__ {`
		`  UART_UNIT_0 = 0,`
		`  UART_UNIT_1,`
		`  UART_UNIT_MAX`
		`} UART_UNIT_IDX;`
		Normally, UART0 is used for debug console, and UART1 is used for data transfer.

int UART_INIT (HANDLE handler)		
Parameter	handler	Device handle
Return		TRUE if success, or FALSE if fails.
Description		The UART configuration should be set before this function is called. After this function is called, UART operation starts.
int UART_CHANGE_BAUERATE (HANDLE handler, UINT32 baudrate)		
Parameter	handler	Device handle
	baudrate	Baud rate to set
Return		TRUE if success, or FALSE if fails
Description		This function changes the baud rate of UART during UART operation.
int UART_IOCTL(HANDLE handler, UINT32 cmd, VOID *data)		
Parameter	handler	Device handle
	cmd	Commands are defined in <uart.h> in the DA16200/DA16600 SDK.
	data	Data pointer
Return		TRUE if success, or FALSE if fails

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Item	Description
Description	The user can set the configuration of UART with this function. Configurations of UART should be called before the UART_INIT() function. Commands are as below: ● UART_GET_DEVREG = 1, // get device physical address ● UART_SET_CLOCK, // set base clock ● UART_SET_BAUDRATE, // set baud rate ● UART_GET_BAUDRATE, // get baud rate ● UART_SET_LINECTRL, // set line control ● UART_GET_LINECTRL, // get line control ● UART_SET_CONTROL, // set UART control ● UART_GET_CONTROL, // get UART control ● UART_SET_SW_RX_QUESIZE, // set queue size ● UART_SET_INT, // set interrupt configuration ● UART_GET_INT, // get interrupt configuration ● UART_SET_FIFO_INT_LEVEL, // set FIFO level ● UART_GET_FIFO_INT_LEVEL, // get FIFO level ● UART_SET_USE_DMA, // set DMA use ● UART_GET_USE_DMA, // get DMA use ● UART_CHECK_RXEMPTY, // check RX FIFO empty ● UART_CHECK_RXFULL, // check RF FIFO full ● UART_CHECK_TXEMPTY, // check TX FIFO empty ● UART_CHECK_TXFULL, // check TX FIFO full ● UART_CHECK_BUSY, // check UART busy ● UART_SET_RX_SUSPEND, // set the RX function to suspend ● UART_GET_RX_SUSPEND, // get the RX function to suspend ● UART_SET_SW_FLOW_CONTROL, // set the flow control to enable ● UART_GET_SW_FLOW_CONTROL, // get the flow control to enable ● UART_SET_WORD_ACCESS, // set word-access-enable register ● UART_GET_WORD_ACCESS, //get word-access-enable register ● UART_SET_RW_WORD, // set whether write and read in word or byte ● UART_GET_RW_WORD, // get whether write and read in word or byte ● UART_SET_RS485, // set the RS485 function to enable ● UART_GET_RS485, // get the RS485 function to enable ● UART_CLEAR_ERR_INT_CNT, // clear error interrupt counter ● UART_GET_ERR_INT_CNT, // get error interrupt counter ● UART_SET_ERR_INT_CALLBACK, // set error interrupt callback function ● UART_CLEAR_FRAME_INT_CNT, //clear frame error interrupt counter ● UART_GET_FRAME_INT_CNT, // get frame error interrupt counter ● UART_SET_FRAME_INT_CALLBACK, // set frame error interrupt callback ● UART_CLEAR_PARITY_INT_CNT, // clear parity error interrupt counter ● UART_GET_PARITY_INT_CNT, // get frame error interrupt counter ● UART_SET_PARITY_INT_CALLBACK, // set frame error interrupt callback ● UART_CLEAR_BREAK_INT_CNT, // clear break error interrupt counter ● UART_GET_BREAK_INT_CNT, // get break error interrupt counter ● UART_SET_BREAK_INT_CALLBACK, // set break error interrupt callback ● UART_CLEAR_OVERRUN_INT_CNT, // clear overrun error interrupt counter ● UART_GET_OVERRUN_INT_CNT, // get overrun error interrupt counter ● UART_SET_OVERRUN_INT_CALLBACK, // set overrun interrupt callback

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Item		Description
int UART_READ (HANDLE handler, VOID *p_data, UINT32 p_dlen)		
Parameter	handler	Device handle
	p_data	Data pointer
	p_dlen	Length to read
Return		If succeeded return number of received data, else negative number.
Description		User can use the UART_SET_RX_SUSPEND ioctl command to set the UART READ operation to suspend or not.
int UART_WRITE (HANDLE handler, VOID *p_data, UINT32 p_dlen)		
Parameter	handler	Device handle
	p_data	Data pointer
	p_dlen	Length to write
Return		Number of sent data.
Description		UART write command
int UART_DMA_READ_TIMEOUT (HANDLE handler, VOID *p_data, UINT32 p_dlen, UINT32 timeout)		
Parameter	handler	Device handle
	p_data	Data pointer
	p_dlen	Length to read
	timeout	Wait option to receive data
Return		Number of received data.
Description		The operation of this function is the same with UART_DMA_READ with waiting timeout.
int UART_DMA_READ (HANDLE handler, VOID *p_data, UINT32 p_dlen)		
Parameter	handler	Device handle
	p_data	Data pointer
	p_dlen	Length to read
Return		Number of received data.
Description		The operation of this function is the same with UART_READ, except DMA is used.
int UART_DMA_WRITE (HANDLE handler, VOID *p_data, UINT32 p_dlen)		
Parameter	handler	Device handle
	p_data	Data pointer
	p_dlen	Length to write
Return		Number of sent data.
Description		The operation of this function is same with UART_WRITE, except DMA is used.
int UART_FLUSH(HANDLE handler)		
Parameter	handler	Device handle
Return		TRUE if success, or FALSE if fails.
Description		Flush the FIFO buffer of UART
int UART_CLOSE(HANDLE handler)		
Parameter	handler	Device handle
Return		TRUE if success, or FALSE if fails.

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Item	Description
Description	UART driver close command

16.1.3 How to Run

1. In the e²studio, import a project for the UART sample application as follows:
   - *~/SDK/apps/common/examples/Peripheral/UART1/projects/da16200*
2. Build the DA16200 SDK, download the RTOS image to the DA16200 EVB, and reboot.
3. The start log message is shown in the console terminal and UART1 terminal.
4. To test with UART1, input test data (hexa or ascii) on the UART1 terminal and click the Enter key to send data to DA16200. Then the console terminal shows the received data in hexadecimal and sends the message "- Data receiving OK…" to UART1.
   a. UART1 terminal

```
- Start UART1 communicate module ...
hello
- Data receiving OK...
```

Figure 108: Result of UART #1

   b. Console terminal

```
- Start UART1 communicate module ...
!!! No selected network !!!

>>> Network Interface (wlan0) : UP
>>> Associated with 70:3a:cb:25:f5:f8

Connection COMPLETE to 70:3a:cb:25:f5:f8

-- DHCP Client WLAN0: SEL(6)
-- DHCP Client WLAN0: REQ(1)
-- DHCP Client WLAN0: CHK(8)
-- DHCP Client WLAN0: BOUND(10)
        Assigned addr    : 192.168.86.68
              netmask    : 255.255.255.0
              gateway    : 192.168.86.1
              DNS addr   : 192.168.86.1

        DHCP Server IP   : 192.168.86.1
        Lease Time       : 24h 00m 00s
        Renewal Time     : 12h 00m 00s

>>>
- (len=5):
[00000000]  68 65 6c 6c 6f                                        hello
```

Figure 109: Result of UART #2

16.1.4 Sample Code

16.1.4.1 Application Initialization

This is an example of a user application to initialize and communicate between the DA16200 and an MCU that is connected through the UART1 interface. Function user_uart1_init() initializes the UART1 H/W resource and then uart1_monitor_sample() is run to communicate with the host through the UART1 interface.

~/SDK/apps/common/examples/Peripheral/UART1/src/uart_sample.c

```
/* Local static variables */
static int  sample_uart_idx = UART_UNIT_1;    // UART_UNIT_1, UART_UNIT_2
```

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```
/*
 * For configuring UART devices,
 *
 * "user_UART_config_info" data should be located in /SDK/customer/src/user_uart.c.
 *
 * This data is temporary for sample application.
 */
static uart_info_t sample_UART_config_info =
{
    UART_BAUDRATE_115200,    /* baud */
    UART_DATABITS_8,         /* bits */
    UART_PARITY_NONE,        /* parity */
    UART_STOPBITS_1,         /* stopbit */
    UART_FLOWCTL_OFF         /* flow control */
};

void run_uart1_sample(UINT32 arg)
{
    int status;

    *
    * int set_user_UART_conf(int uart_idx, uart_info_t *uart_conf_info, char
      atcmd_flag)
    */
    status = set_user_UART_conf(UART_UNIT_1, &sample_UART_config_info, FALSE);
    if (status != 0)
    {
        PRINTF("[%S] Error to configure for UART1 !!!\n", __func__);
        return;
    }


    *
    * int UART_init(int uart_idx);
    */
    status = UART_init(sample_uart_idx);
    if (status != 0)
    {
        PRINTF("[%S] Error to initialize UART1 with sample_UART_config !!!\n",
        __func__);
    return;
    }

    /* Start UART monitor */
    uart1_sample();
}
```

Function uart1_sample() invokes function *get_data_from_uart1()* repeatedly to read data from UART1. User can enable/disable the UART echo function by setting “echo_enable”.

```
static void uart1_sample(void)
{
    int i;
    char *init_str = "- Start UART1 communicate module ...\r\n";
    char *rx_buf = NULL;
    char *tx_buf = "\r\n- Data receiving OK...\r\n";
    int tx_len;


    /* Print-out test string to console and to UART1 device */
```

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```
    PRINTF((const char *)init_str); // For Console
    puts_UART(sample_uart_idx, init_str, strlen((const char *)init_str));

    echo_enable = TRUE;
    rx_buf = malloc(USER_UART1_BUF_SZ);

    while (1)
    {
        memset(rx_buf, 0, USER_UART1_BUF_SZ);

        /* Get on byte from uart1 comm port */
        get_data_from_uart1(rx_buf);
        … …
    }
}
```

16.1.4.2 Data Read/Write

Use getchar_UART() to read a character from UART1 or UART2. This example shows how to read data from UART device until meets characters '\n' or '\r'. User can modify this function for customized application operation.

NOTE
After UART_INIT() is called, it tries to receive UART_RX data even if UART_READ() does not call. Flush the UART_RX data if there is no need to use data before UART_READ().

```
#define USER_DELIMITER_0    '\0'
#define USER_DELIMITER_1    '\n'
#define USER_DELIMITER_2    '\r'

static void get_data_from_uart1(char *buf)
{
    char    ch = 0;
    int     i = 0;

    while (1) {
        /* Get on byte from uart1 comm port */
        ch = getchar_UART(sample_uart_idx, portMAX_DELAY);

        if (ch == 0) {
            vTaskDelay(1);
            continue;
        }

        if (echo_enable == TRUE) {
            puts_UART(sample_uart_idx, &ch, sizeof(char)); // echo
        }

        /* check data length */
        if (i >= (USER_UART1_BUF_SZ - 1)) {
            i = USER_UART1_BUF_SZ - 2;
        }

        if (ch == USER_DELIMITER_1 || ch == USER_DELIMITER_2) {
            buf[i++] = USER_DELIMITER_0;
            break;
        } else {
            buf[i++] = ch;
```

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```
            }
        }
    }
```

And also, this example shows how to send data to UART1 using by puts_UART() API.

~/SDK/core/system//include/common/common_uart.h

```
/**
 ******************************************************************************
 * @brief  Put character string to UART device
 * @param[in] uart_idx  Index value of UART interface (UART_UNIT_1,  UART_UNIT_2)
 * @param[in] *data     Text string to write
 * @param[in] len       Write length
 * @return              None
 ******************************************************************************
 */
void    puts_UART(int uart_idx, char *data, int data_len);
```

16.2 GPIO

This application shows how to read/write the GPIO port and use the GPIO interrupt.

16.2.1 Introduction

All digital pads can be used as GPIO. Each GPIO port is mixed with a multi-functional interface. The GPIO features for this device are:

- Input or output lines in a programmable direction
- Word and half word read/write access
- Address-masked byte writes to facilitate quick bit set and clear operations
- Address-based byte reads to facilitate quick bit test operations
- Make a GPIO pin to an interrupt pin possible to be the output signal of PWM [3:0], external Interrupt, SPI_CSB [3:1], RF_SW [1:0] and UART_TXDOE [1:0] on any GPIO pin

It provides special functions for GPIO pin use. PWM [3:0], external interrupt, SPI_CSB [3:1], RF_SW [1:0] and UART_TXDOE [1:0] signals can be output if any of the unused pins among the GPIO pins are selected. It is possible to select the function to be output from the GPIO register setting and select the remaining GPIO pin and not output the specific function to any desired GPIO pin.

Table 58: GPIO Pin Configuration

Pin Name	Pin Number	I/O	Pin Selection	Function Name
GPIOA0	39	I/O	Reg. GPIO_SEL.AMUX9	GPIOA[0]
GPIOA1	38	I/O	Reg. GPIO_SEL.AMUX9	GPIOA[1]
GPIOA2	37	I/O	Reg. GPIO_SEL.BMUX9	GPIOA[2]
GPIOA3	36	I/O	Reg. GPIO_SEL.BMUX9	GPIOA[3]
GPIOA4	34	I/O	Reg. GPIO_SEL.CMUX9	GPIOA[4]
GPIOA5	33	I/O	Reg. GPIO_SEL.CMUX9	GPIOA[5]
GPIOA6	32	I/O	Reg. GPIO_SEL.DMUX9	GPIOA[6]
GPIOA7	31	I/O	Reg. GPIO_SEL.DMUX9	GPIOA[7]
GPIOA8	30	I/O	Reg. GPIO_SEL.EMUX9	GPIOA[8]
GPIOA9	29	I/O	Reg. GPIO_SEL.EMUX9	GPIOA[9]

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Pin Name	Pin Number	I/O	Pin Selection	Function Name
GPIOA10	28	I/O	Reg. GPIO_SEL.FMUX7	GPIOA[10]
GPIOA11	27	I/O	Reg. GPIO_SEL.FMUX7	GPIOA[11]
GPIOC6	10	I/O	Reg. GPIO_SEL.UMUX2	GPIOC[6]
GPIOC7	9	I/O	Reg. GPIO_SEL.UMUX2	GPIOC[7]
GPIOC8	8	I/O	Reg. GPIO_SEL.UMUX2	GPIOC[8]

When keeping GPIO PIN state high or low in sleep state, use one of the following API functions:

- _GPIO_RETAIN_HIGH()
- _GPIO_RETAIN_LOW()

Note that only GPIOA [11:4] and GPIOC [8:6] can be set as GPIO retention high or low. When using GPIO and GPIO Retention API, the status of GPIO PIN is shown in Table 59.

Table 59: Status of GPIO PIN

	PIN Info	Before sleep (RTOS Booting)	Sleep Period	Sleep Period (with SAVE_PULLUP_PINS_INFO)	After Sleep (wakeup)
GPIO input configured	GPIOA[3:0]	high-z	high-z	high-z	I-PD
	GPIOA[11:8], GPIOC[8:6]	high-z	low (PD)	high-z	I-PD
GPIO output high configured	GPIOA[3:0]	high	high-z	high-z	I-PD
	GPIOA[11:8], GPIOC[8:6]	high	low (PD)	high-z	I-PD
GPIO output low configured	GPIOA[3:0]	low	high-z	high-z	I-PD
	GPIOA[11:8], GPIOC[8:6]	low	low (PD)	high-z	I-PD
GPIO retention high configured	GPIOA[11:8], GPIOC[8:6]	high	high	high	high
GPIO retention low configured	GPIOA[11:8], GPIOC[8:6]	low	low	low	low

When keeping GPIO PIN in high-z state in sleep period, use the API described in the Section 16.2.2:

- SAVE_PULLUP_PINS_INFO()

This function should be used when an external pull-up register is connected to a GPIO PIN. If this function is not used, leakage current may occur.

16.2.2 API

Table 60: APIs for GPIO Interface

Item		Description
HANDLE GPIO_CREATE(UINT32 dev_type)		
Parameter	dev_type	Device index
Return		If succeeded, return handle for the device. If failed return NULL.
Description		The DA16200/DA16600 can set GPIO_UNIT_A and GPIO_UNIT_C.

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Item		Description
int GPIO_INIT (HANDLE handler)		
Parameter	handler	Device handle
Return		TRUE if success, or FALSE if fails.
Description		Configure the GPIO setting
int GPIO_IOCTL(HANDLE handler, UINT32 cmd, VOID *data)		
Parameter	handler	Device handle
	cmd	Commands are defined <gpio.h> in our SDK.
	data	Data pointer
Return		TRUE if success, or FALSE if fails.
Description		The necessary configuration of GPIO can be set with this function. Commands are as below: ● GPIO_GET_DEVREG = 1, ● GPIO_SET_OUTPUT, // set gpio as an output ● GPIO_SET_INPUT, // set gpio as an input ● GPIO_GET_DIRECTION, // get gpio direction ● GPIO_SET_INTR_MODE, // set gpio interrupt mode [edge/level] ● GPIO_GET_INTR_MODE, // get gpio interrupt mode ● GPIO_SET_INTR_ENABLE, // enable gpio interrupt ● GPIO_SET_INTR_DISABLE, // disable gpio interrupt ● GPIO_GET_INTR_ENABLE, // get gpio interrupt enable status ● GPIO_GET_INTR_STATUS, // get gpio interrupt pending status ● GPIO_SET_INTR_CLEAR, // clear gpio interrupt status ● GPIO_SET_MODE_ALT, // set alternate function ● GPIO_SET_MODE_NOALT, // clear alternate function ● GPIO_GET_MODE_ALT, // get alternate function ● GPIO_SET_CALLACK, // set a callback function for gpio interrupt
int GPIO_READ (HANDLE handler, UINT32 addr, UINT16 *pdata, UINT32 dlen)		
Parameter	handler	Device handle
	addr	GPIO index
	p_data	Data buffer pointer
	p_dlen	Data buffer length
Return		TRUE if success, or FALSE if fails
Description		GPIO value contained in p_data
int GPIO_WRITE (HANDLE handler, UINT32 addr, VOID *p_data, UINT32 p_dlen)		
Parameter	handler	Device handle
	addr	GPIO index
	p_data	Data buffer pointer
	p_dlen	Data buffer length
Return		TRUE if success, or FALSE if fails.
Description		GPIO value contained in p_data
int GPIO_CLOSE(HANDLE handler)		
Parameter	handler	Device handle

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Item		Description
Return		TRUE if success, or FALSE if fails.
Description		GPIO close command
INT32 GPIO_GET_ALT_FUNC (HANDLE handler, GPIO_ALT_FUNC_TYPE altFuncType, UINT32 * regVal)		
Parameter	handler	Device handle
	altFuncType	GPIO alternate function type
	regVal	GPIO alternate function setting value
Return		If succeeded, return 0.
Description		Gets GPIO alternate function setting value.
INT32 GPIO_SET_ALT_FUNC(HANDLE handler, GPIO_ALT_FUNC_TYPE altFuncType, GPIO_ALT_GPIO_NUM_TYPE gpioType)		
Parameter	handler	Device handle
	altFuncType	GPIO alternate function type
	gpioType	GPIO number
Return		If succeeded, return 0.
Description		Sets GPIO alternate function
INT32 _GPIO_RETAIN_HIGH(UINT32 gpio_port, UINT32 gpio_num)		
Parameter	gpio_port	GPIO port number
	gpio_num	GPIO pin number
Return		TRUE if successfully configured, else FALSE.
Description		Note that only for GPIOA[11:4], GPIOC[8:6] is possible to set GPIO retention high. And this API function should not be called from the “config_pin_mux” function.
INT32 _GPIO_RETAIN_LOW(UINT32 gpio_port, UINT32 gpio_num)		
Parameter	gpio_port	GPIO port number
	gpio_num	GPIO pin number
Return		TRUE if successfully configured, else FALSE.
Description		Note that only for GPIOA[11:4], GPIOC[8:6] is possible to set GPIO retention high. And this API function should not be called from the “config_pin_mux” function.
void SAVE_PULLUP_PINS_INFO(UINT32 port_num, UINT32 pinnum)		
Parameter	port_num	GPIO port number
	pinnum	GPIO pin number
Description		It keeps GPIO PIN in high-z state in sleep period. This function should be used when an external pull-up register is connected to a GPIO PIN. If this function is not used, leakage current may occur.

16.2.3 How to Run

1. In the e²studio, import a project for the GPIO sample application as follows:
   - *~/SDK/apps/common/examples/Peripheral/GPIO/projects/da16200*
2. Build the DA16200 SDK, download the RTOS image to the DA16200 EVB, and reboot.
3. The status of GPIOA[0] and GPIOA[1] is printed every 1 second.

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- GPIOA[0] output low, GPIOA[4] output low, GPIOA[1] input low
- GPIOA[0] output high, GPIOA[4] output high, GPIOA[1] input low
- GPIOA[0] output low, GPIOA[4] output low, GPIOA[1] input low

16.2.4 Sample Code

1. Create and initialize a GPIO handle.

```
HANDLE gpio;
gpio = GPIO_CREATE(GPIO_UNIT_A);
GPIO_INIT(gpio);
```

2. Set pin multiplexing.

```
/* AMUX to GPIOA[1:0] */
_da16x_io_pinmux(PIN_AMUX, AMUX_GPIO);

/* BMUX to GPIOA[3:2] */
_da16x_io_pinmux(PIN_BMUX, BMUX_GPIO);

/* CMUX to GPIOA[5:4] */
_da16x_io_pinmux(PIN_CMUX, CMUX_GPIO);
```

3. Set GPIOA[0] and GPIOA[4] as output mode and GPIOA[1] as input mode.

```
/* GPIOA[0],GPIOA[4] output high low toggle */
pin = GPIO_PIN0 | GPIO_PIN4;
GPIO_IOCTL(gpio, GPIO_SET_OUTPUT, &pin); /* GPIOA[1] input */
pin = GPIO_PIN1;
GPIO_IOCTL(gpio, GPIO_SET_INPUT, &pin);
```

4. Set GPIOA[2] as an interrupt source with active low and register a callback function.

```
static int set_gpio_interrupt(HANDLE handler, UINT8 pin_num, UINT8 int_type, UINT8
int_pol, void *callback_func)
{
      UINT16 pin, int_en_status;
      UINT32 ioctldata[3];
      int ret;

      if (15 < pin_num )
       return FALSE;

      if(handler == NULL){
       return FALSE;
      }

      pin = 0x01<<pin_num;
      ret = GPIO_IOCTL(handler, GPIO_SET_INPUT, &pin);

      ret = GPIO_IOCTL(handler, GPIO_GET_INTR_MODE, &ioctldata[0]);
      /* interrupt type 1: edge, 0: level*/
      ioctldata[0] &= ~(1 << pin_num); // clear the bit first
      ioctldata[0] |= (int_type << pin_num);
      /* interrupt pol 1: high active, 0: low active */
      ioctldata[1] &= ~(1 << pin_num); // clear the bit first
      ioctldata[1] |= (int_pol << pin_num);
      ret = GPIO_IOCTL(handler, GPIO_SET_INTR_MODE, &ioctldata[0]);

      /* register callback function */
      ioctldata[0] = pin; /* interrupt pin */
      ioctldata[1] = (UINT32) callback_func; /* callback function */
```

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```
        ioctldata[2] = (UINT32) pin_num; /* param data */
        ret = GPIO_IOCTL(handler, GPIO_SET_CALLACK, ioctldata);

        ret = GPIO_IOCTL(handler, GPIO_GET_INTR_ENABLE, &int_en_status);
        int_en_status |= pin;
        ret = GPIO_IOCTL(handler, GPIO_SET_INTR_ENABLE, &int_en_status);

        return ret;
}

/* GPIOA[2] interrupt active low , Edge trigger */
set_gpio_interrupt(gpio, 2, GPIO_INT_TYPE_EDGE, GPIO_INT_POL_LOW, (void*)gpio_callback );
```

5. Set GPIOA[3] as an interrupt source with active high and register a callback function.

```
/*GPIOA[3] interrupt active high, Edge trigger */
set_gpio_interrupt(gpio, 3, GPIO_INT_TYPE_EDGE, GPIO_INT_POL_HIGH, (void*)gpio_callback );
```

6. Write GPIOA[0] and GPIOA[4] and read GPIOA[1].

```
if (toggle) {
    /* GPIOA[0],GPIOA[4] to high */
    write_data = GPIO_PIN0 | GPIO_PIN4;
    GPIO_WRITE(gpio, GPIO_PIN0 | GPIO_PIN4, &write_data, sizeof(UINT16));
    toggle = 0;
} else {
    /* GPIOA[0],GPIOA[4] to low*/
    write_data = 0;
    GPIO_WRITE(gpio, GPIO_PIN0 | GPIO_PIN4, &write_data, sizeof(UINT16));
    toggle = 1;
}

GPIO_READ(gpio, GPIO_PIN1, &read_data, sizeof(UINT16));
```

7. Set the PAD pull condition by using PAD_PULL_CONTROL.

```
#if PAD_PULL_CONTROL
    /*
       * GPIOA[1] input pull control it can make gpio pad pull up or pull down or HIZ
    */
    _da16x_gpio_set_pull(GPIO_UNIT_A, GPIO_PIN1, PULL_UP);
    /* or */
    _da16x_gpio_set_pull(GPIO_UNIT_A, GPIO_PIN1, PULL_DOWN);
    /* or */
    _da16x_gpio_set_pull(GPIO_UNIT_A, GPIO_PIN1, HIGH_Z);
#endif
```

8. Activate the RTC_GPO example by using RTC_GPO_CONTROL.

```
#ifdef RTC_GPO_CONTROL
     RTC_GPO_OUT_INIT(1);                // 0: auto, 1: manual
     RTC_GPO_OUT_CONTROL(1);              // Set High
#endif
```

9. Both edges of interrupt are not supported by HW, but can be supported by SW.

   Activate the GPIO interrupt according to the GPIO read value.

```
GPIO_READ(gpioc, GPIO_PIN6, &read_data, sizeof(UINT16));
set_gpio_interrupt(gpioc, 6, GPIO_INT_TYPE_EDGE, !(GPIO_PIN6&read_data),
(void*)gpioc_callback );
```

   And change the interrupt polarity at every GPIO callback function.

   See the “GPIOC6_BOTH_EDGE_INTERRUPT” example for this

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16.3 GPIO Retention

This application shows how to use GPIO retention. If the GPIO pin is set to retention high, it is kept in the high state during the sleep period. If the GPIO pin is set to retention low, it is kept in the low state during the sleep period.

16.3.1 How to Run

1. In the e²studio, import a project for the GPIO Retention sample application as follows:
   ~/SDK/apps/common/examples/Peripheral/GPIO_Retention/projects/da16200
2. Build the main project, download the image to the DA16200 EVB, and reboot.
3. Toggle switch 13 (SW13).
4. Use an oscilloscope to check that the GPIOA [10: 8] and GPIOC [7] keep their PIN states.

16.3.2 Sample Code

1. Set pin multiplexing.

```
/*
 * 1. Set to GPIOA[11:8], GPIOC[8:6]
 * 2. Need be written to "config_pin_mux" function.
 */
_da16x_io_pinmux(PIN_EMUX, EMUX_GPIO);
_da16x_io_pinmux(PIN_FMUX, FMUX_GPIO);
_da16x_io_pinmux(PIN_UMUX, UMUX_GPIO);
```

2. Set GPIO retention config.

```
/* Set GPIOA[9:8] to retention high */
ret = _GPIO_RETAIN_HIGH(GPIO_UNIT_A, GPIO_PIN8 | GPIO_PIN9);
if(ret == FALSE)
    PRINTF("GPIO_RETAIN_HIGH() return false.\n");

/* Set GPIOA[10] to retention low */
ret = _GPIO_RETAIN_LOW(GPIO_UNIT_A, GPIO_PIN10);
if (ret == FALSE)
    PRINTF("GPIO_RETAIN_LOW() return false.\n");

/* Set GPIOC[7] to retention high */
ret = _GPIO_RETAIN_HIGH(GPIO_UNIT_C, GPIO_PIN7);
if(ret == FALSE)
    PRINTF("GPIO_RETAIN_HIGH() return false.\n");
```

3. Power down.

```
char * _argv[4] = {"down", "sec", "10", "1"};
cmd_power_down_config(4, _argv);

/* Set GPIOC[7] to retention high */
ret = _GPIO_RETAIN_HIGH(GPIO_UNIT_C, GPIO_PIN7);
if(ret == FALSE)
    PRINTF("GPIO_RETAIN_HIGH() return false.\n");
```

16.4 I2C

This section shows how to use the I2C interface.

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16.4.1 Introduction

16.4.1.1 I2C Master

The DA16200/DA16600 includes an I2C master module. There are two supportable clock speeds for I2C in the DA16200/DA16600; the standard speed is 100 kbps and fast mode is 400 kbps.

Table 61 shows the pin definition of the I2C master interface in GPIO Pin Configuration.

Table 61: I2C Master Pin Configuration

Pin Name	Pin Number		I/O	Function Name
	QFN	fcCSP		
GPIOA1	38	C3	O	I2C_CLK
GPIOA5	33	D2	O	
GPIOA9	29	H2	O	
GPIOA0	39	A3	I/O	I2C_SDA
GPIOA4	34	F4	I/O	
GPIOA8	32	G3	I/O	

For more details, see the datasheet Ref. [2].

16.4.1.2 I2C Slave

The DA16200/DA16600 support the I2C slave interface controlled by an external host. The pin mux configurations are defined in Table 62. The I2C slave interface also supports the standard (100 kbps) or fast (400 kbps) transmission speeds.

Table 62: I2C Slave Pin Configuration

Pin Name	Pin Number		I/O	Function Name
	QFN	fcCSP		
GPIOA1	38	C3	I	I2C_CLK
GPIOA3	36	D4	I	
GPIOA5	33	D2	I	
GPIOA7	31	E1	I	
GPIOA0	39	A3	I/O	I2C_SDA
GPIOA2	37	B2	I/O	
GPIOA4	34	F4	I/O	
GPIOA6	32	E3	I/O	

For more details, see the datasheet Ref. [2].

16.4.2 API

Table 63: APIs for I2C Interface

Item		Description
HANDLE DRV_I2C_CREATE(UINT32 dev_id)		
Parameter	dev_id	Device ID number to create a handle
Return		If succeeded, return handle for the device. If failed, return NULL.

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Item		Description	
Description		Create a handle with parameter "dev_id" designated	
Int DRV_I2C_INIT(HANDLE handler)			
Parameter	handler	Device handle to initialize	
Return		If succeeded, return TRUE. If failed, return FALSE.	
Description		Initialize the I2C interface.	
int DRV_I2C_IOCTL(HANDLE handler, UINT32 cmd, VOID *data)			
Parameter	handler	Device handle to control	
	cmd	See <sys_i2c.h> in our SDK	
	*data	Data pointer when there is any. If not, NULL	
Return		If succeeded, return TRUE. If failed, return FALSE.	
Description		This function will control miscellaneous I2C controller.	
int DRV_I2C_IOCTL(HANDLE handler, UINT32 cmd, VOID *data)			
I2C_GET_CONFIG		Get "i2c_cr0" Register Value. See Register Map	Read
I2C_GET_STATUS		Get "i2c_sr" Register Value. See Register Map	Read
I2C_SET_DMA_WR		I2C Write via uDMA TX Enable / Disable	[TRUE / FALSE]
I2C_SET_DMA_RD		I2C READ via uDMA RX Enable / Disable	[TRUE / FALSE]
I2C_GET_DMA_WR		Get uDMA TX Enabled	[0x2 / FALSE]
I2C_GET_DMA_RD		Get uDMA RX Enabled	[TRUE / FALSE]
I2C_SET_RESET		Set I2C Device Reset / set	[TRUE / FALSE]
I2C_SET_CHIPADDR		Set I2C Slave Device Address (8 bits)	Write
I2C_GET_CHIPADDR		Get I2C Slave Device Address (8 bits)	Read
I2C_SET_CLOCK		Set I2C Clock [kHz] (Max = 1200)	Write
int DRV_I2C_WRITE_DMA(HANDLE handler, VOID *p_data, UINT32 p_dlen, UINT32 dummy)			
Parameter	handler	Device handle to write with DMA	
	*p_data	Buffer pointer to write	
	p_dlen	Length to write	
	dummy	Reserved (set to ‘0’)	
Return		If succeeded, return TRUE. If failed, return FALSE.	
Description		I2C write function through DMA	
int DRV_I2C_WRITE(HANDLE handler, VOID *p_data, UINT32 p_dlen, UINT32 stopen, UINT32 dummy)			
Parameter	handler	Device handle to write	
	*p_data	Buffer pointer to write	
	p_dlen	Length to read	
	stopen	Flag stop bit enable	
	dummy	Reserved (set to ‘0’)	
Return		If succeeded, return TRUE. If failed, return FALSE.	
Description		I2C write function	
int DRV_I2C_READ(HANDLE handler, VOID *p_data, UINT32 p_dlen, UINT32 addr_len,UINT32 dummy)			
Parameter	handler	Device handle to read	

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Item		Description
	*p_data	Buffer pointer to read
	p_dlen	Length to read
	addr_len	Length of register address inside of slave device. if 0, Read only operation
	dummy	Reserved (set to '0')
Return		If succeeded, return TRUE. If failed, return FALSE.
Description		I2C read function
Int DRV_I2C_CLOSE(HANDLE handler);		
Parameter	handler	Device handle to close
Return		If succeeded, return TRUE. If failed, return FALSE.
Description		I2C driver close
void DRV_I2C_REGISTER_INTERRUPT(HANDLE handler);		
Parameter	handler	Device handle to register Interrupt Handler
Return		NULL
Description		I2C Interrupt Registration

16.4.3 How to Run

1. In the e²studio, import a project for the I2C sample application as follows:
   - *~/SDK/apps/common/examples/Peripheral/I2C/projects/da16200*
2. Build the DA16200 SDK, download the RTOS image to the DA16200 EVB, and reboot.
3. The sample application code is written in the following source file:
   ~/SDK/apps/common/examples/Peripheral/I2C/src/i2c_sample.c

16.4.3.1 Test Procedure

1. Remove resistor R6 and R7.
2. Connect the AT24C512 EEPROM with the Renesas EVK.
3. Connect each 1,2 kΩ Pull-Up resistor with GPIOA0 and GPIOA1.
   GPIOA0= SDA, GPIOA1=SCL
4. Run I2C example code.

16.4.3.2 Sample Code for Using I2C

1. Initialize I2C.

```
// GPIO Select for I2C working. GPIO1 = SCL, GPIO0= SDA
Board_initialization();
DA16X_CLOCK_SCGATE->Off_DAPB_I2CM = 0;
DA16X_CLOCK_SCGATE->Off_DAPB_APBS = 0;

// Create Handle for I2C Device
I2C = DRV_I2C_CREATE(i2c_0);

// Initialization I2C Device
DRV_I2C_INIT(I2C);
```

2. I2C address.

```
// Device Address for AT24C512
UINT32 addr = 0xa0;
```

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```
DRV_I2C_IOCTL(I2C, I2C_SET_CHIPADDR, &addr);
```

3. I2C clock.

```
// Set I2C Working Clock. Unit = kHz
DRV_I2C_IOCTL(I2C, I2C_SET_CLOCK, &i2c_clock);
```

4. Write I2C.

```
// Data Random Write  to EEPROM
// Address = 0, Length = 32, Word Address Length = 2
// [Start] - [Device addr. W] -  [1st word addr.] - [2nd word addr.] - [wdata0] ~
   [wdata31] - [Stop]

i2c_data[0] = AT_I2C_FIRST_WORD_ADDRESS; //Word Address to Write Data. 2 Bytes.
                                          refer at24c512 DataSheet
i2c_data[1] = AT_I2C_SECOND_WORD_ADDRESS; //Word Address to Write Data. 2 Bytes.
                                          refer at24c512 DataSheet

// Fill Ramp Data
for (int i = 0; i < AT_I2C_DATA_LENGTH; i++) {
    i2c_data[i+AT_I2C_LENGTH_FOR_WORD_ADDRESS] = i;
}

status = DRV_I2C_WRITE(I2C, i2c_data,
// Handle, buffer, length, stop enable, dummy
AT_I2C_DATA_LENGTH + AT_I2C_LENGTH_FOR_WORD_ADDRESS, 1, 0);

if (status != TRUE) {
    PRINTF("ret : 0x%08x\r\n", status);
}
```

5. Read I2C.

```
// Data Random Read  from EEPROM
// Address = 0, Length = 32, Word Address Length = 2
// [Start] - [Device addr. W] - [1st word addr.] - [2nd word addr.]  - [Start] -
   [Device addr. R] - [rdata0] ~ [rdata31] - [Stop]

// Word Address to Write Data. 2 Bytes. refer at24c512 DataSheet
i2c_data_read[0] = AT_I2C_FIRST_WORD_ADDRESS;

//Word Address to Write Data. 2 Bytes. refer at24c512 DataSheet
i2c_data_read[1] = AT_I2C_SECOND_WORD_ADDRESS;

// Handle, buffer, length, address length, dummy
status = DRV_I2C_READ(I2C, i2c_data_read, AT_I2C_DATA_LENGTH,
                      AT_I2C_LENGTH_FOR_WORD_ADDRESS, 0);

if (status != TRUE) {
    PRINTF("ret : 0x%08x\r\n", status);
}

// Check Data
for (int i = 0; i < AT_I2C_DATA_LENGTH; i++) {
    if (i2c_data_read[i] != i2c_data[i + AT_I2C_LENGTH_FOR_WORD_ADDRESS]) {
        PRINTF("%dth data is different W:0x%02x, R:0x%02x\r\n", i,
                i2c_data[i + AT_I2C_LENGTH_FOR_WORD_ADDRESS],
                i2c_data_read[i]);
        status = AT_I2C_ERROR_DATA_CHECK;
    }
}
```

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```
if (status != AT_I2C_ERROR_DATA_CHECK) {
    PRINTF("***** 32 Bytes Data Write and Read Success *****\r\n");
}
```

6. I2C read_nostop.

```
// Data Current Address  Read from EEPROM
// Length = 32, Word Address Length = 0
// [Start] -[Device addr. R] - [rdata0] ~ [rdata31] - [Stop]

// Handle, buffer, length, address length, dummy
status = DRV_I2C_READ(I2C, i2c_data_read, 4, 0, 0);

if (status != TRUE) {
    PRINTF("ret : 0x%08x\r\n", status);
}
```

16.5 I2S

This section shows how to use the I2S interface.

16.5.1 How to Run

1. In the e²studio, import a project for the I2S sample application as follows:
   - *~/SDK/apps/common/examples/Peripheral/I2S/projects/da16200*
2. Build the DA16200 SDK, download the RTOS image to the DA16200 EVB, and reboot.
3. The sample application code is written in the following source file:
   ~/SDK/apps/common/examples/Peripheral/I2S/src/i2s_sample.c

16.5.2 User Task

The user task of the I2S application is added as shown in the example below and is executed by the system. SAMPLE_I2S should be a unique name to create a task. The port number does not need to be set, because this is a non-network task.

~/SDK/apps/common/examples/Peripheral/I2S/src/sample_apps.c

```
static const app_task_info_t      sample_apps_table[] =
{ I2S_SAMPLE, i2s_sample, 512, (tskIDLE_PRIORITY + 7), FALSE, FALSE,
  UNDEF_PORT,RUN_ALL_MODE },
};
```

16.5.3 Sample Code

1. Create and initialize an I2S handle.

```
HANDLE gi2shandle = NULL;
I2S_HANDLER_TYPE *i2s;
unsigned int mode, data;

DA16X_CLOCK_SCGATE->Off_DAPB_I2S = 0;
DA16X_CLOCK_SCGATE->Off_DAPB_APBS = 0;

gi2shandle = DRV_I2S_CREATE(I2S_0);
i2s = (I2S_HANDLER_TYPE *) gi2shandle;

if (!gi2shandle) {
    vTaskDelete(NULL);
    return;
```

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```
}

/* Set I2S Output Mode */
if (DRV_I2S_INIT(gi2shandle, mode) == FALSE) {
    vTaskDelete(NULL);
    return;
}
```

2. Set the internal DAC or the external DAC.

```
// GPIO[3] - I2S_LRCK,  GPIO[2] - I2S_SDO
_da16x_io_pinmux(PIN_BMUX, BMUX_I2S);
// GPIO[1] - I2S_MCLK,  GPIO[0] - I2S_BCLK
_da16x_io_pinmux(PIN_AMUX, AMUX_I2S);

DRV_I2S_SET_CLOCK(gi2shandle, I2S_CLK_SOURCE_INTERNAL, 0);
```

3. Set additional configuration.

```
data = TRUE;
DRV_I2S_IOCTL(i2s, I2S_SET_STEREO, &data); /* Set Stereo Output Mode */

#ifdef I2S_SAMPLE_SET_MODE_RX
data = I2S_RESOLUTION_RX_16B;
#else
data = I2S_RESOLUTION_TX_16B;
#endif

DRV_I2S_IOCTL(i2s, I2S_SET_PCM_RESOLUTION, &data); /* Set 16bit resolution Mode */
```

4. Write and read data.

```
for(int i=0;i<2;i++)
{
#ifdef I2S_SAMPLE_SET_MODE_RX
    rd_len = DRV_I2S_READ(i2s, (unsigned int *)rx_buf[i], 768, 0);
#else
    DRV_I2S_WRITE(i2s, (unsigned int *) sinewave_pattern, 768, 0);
#endif
    xEventGroupWaitBits(i2s_sample_event, 0x1, pdTRUE, pdFALSE, 20);
}
```

16.6 PWM

This section shows how to use the PWM interface.

16.6.1 Introduction

Pulse-Width Modulation (PWM) is a modulation technique used to encode a message into a pulse signal. The blocks are designed to adjust the output pulse duration by means of the CPU bus clock (HCLK).

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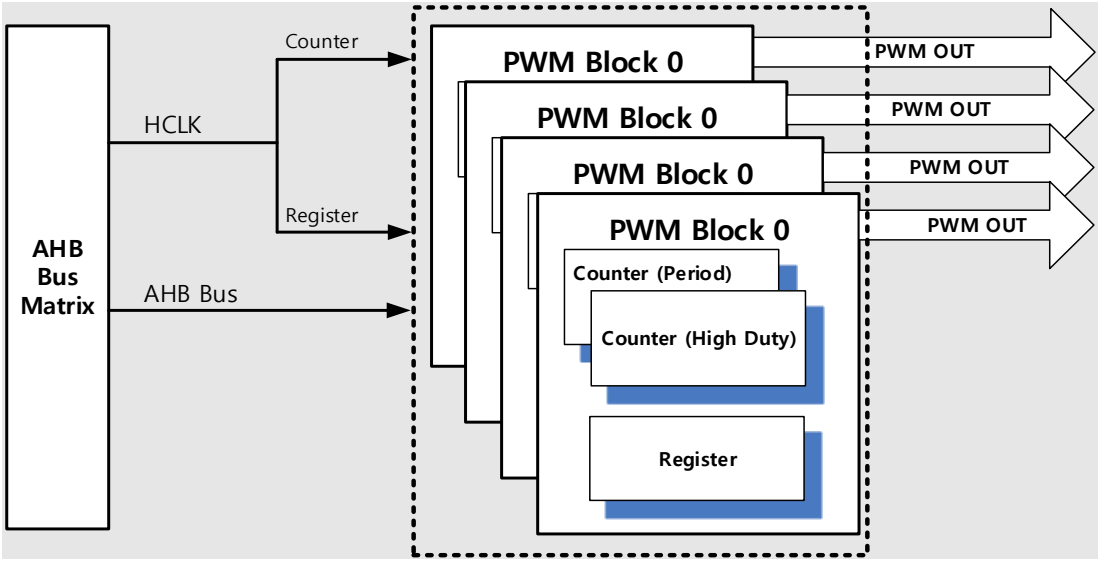

Figure 110: PWM Block Diagram

Table 64: PWM Pin Configuration

Pin Name		Pin Number	I/O	Pin Selection	Function Name
GPIOx			O	Reg. GPIO_SEL.xMUXx	PWM[3:0] output

For more details, see the datasheet Ref. [2].

16.6.2 API

Table 65: APIs for PWM Interface

Item		Description
HANDLE DRV_PWM_CREATE(UINT32 dev_id)		
Parameter	dev_id	Device number to create handle
Return		If succeeded, return handle for such device. If failed, return NULL.
Description		Function create handle with parameter "dev_id" designated
int DRV_PWM_INITf(HANDLE handler)		
Parameter	handler	Device handle to initialize
Return		If succeeded, return TRUE. If failed, return FALSE.
Description		Change GPIO multiplex to PWM mode
int DRV_PWM_START(HANDLE handler, UINT32 period_us, UINT32 hduty_percent, UINT32 dummy)		
Parameter	handler	Device handle to enable pwm device output
	Period_us	1 cycle period in microsecond
	Hduty_percent	Output high time in percentage while every 1 cycle
	dummy	TBD
Return		If succeeded, return TRUE. If failed, return FALSE.

Description		Enable PWM block in the DA16200/DA16600 with specified parameters
		`period = (((period_us * 10) * (clock / 1000000))/10)-1;`
		`// minimum system clock 1 MHz`
		`hduty = (((period + 1) * hduty_percent) / 100)-1;`

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Item		Description
int DRV_PWM_STOP(HANDLE handler, UINT32 dummy)		
Parameter	handler	Device handle to stop pwm out
	cmd	See <pwm.h> in our SDK
Return		If succeeded, return TRUE. If failed, return FALSE.
Description		Disable PWM block in the DA16200/DA16600
int DRV_PWM_CLOSE(HANDLE handler)		
Parameter	handler	Device handle to close and de-initialize device
Return		If succeeded, return TRUE. If failed, return FALSE.
Description		Destroy handle

16.6.3 How to Run

1. In the e²studio, import a project for the PWM sample application as follows:
   - *~/SDK/apps/common/examples/Peripheral/PWM/projects/da16200*
2. Build the DA16200 SDK, download the RTOS image to the DA16200 EVB, and reboot.
3. The sample application code is written in the following source file:
   ~/SDK/apps/common/examples/Peripheral/PWM/src/pwm_sample.c

16.6.3.1 Test Procedure

1. Remove resistor R6~R9.
2. Run the PWM example command.
3. Get waveform from P7~P9 in connector J4.
4. Compare the waveform with the PWM setting inside the example code.

16.6.3.2 Sample Code

1. Set GPIO.

```
Board_Init();
DA16X_CLOCK_SCGATE->Off_CAPB_PWM = 0;

gpio = GPIO_CREATE(GPIO_UNIT_A);
GPIO_INIT(gpio);
GPIO_SET_ALT_FUNC(gpio, GPIO_ALT_FUNC_PWM_OUT0, GPIO_ALT_FUNC_GPIO0);
GPIO_SET_ALT_FUNC(gpio, GPIO_ALT_FUNC_PWM_OUT1, GPIO_ALT_FUNC_GPIO1);
GPIO_SET_ALT_FUNC(gpio, GPIO_ALT_FUNC_PWM_OUT2, GPIO_ALT_FUNC_GPIO2);
GPIO_SET_ALT_FUNC(gpio, GPIO_ALT_FUNC_PWM_OUT3, GPIO_ALT_FUNC_GPIO3);
```

2. Initialize PWM.

```
pwm[0] = DRV_PWM_CREATE(pwm_0);
pwm[1] = DRV_PWM_CREATE(pwm_1);
pwm[2] = DRV_PWM_CREATE(pwm_2);
pwm[3] = DRV_PWM_CREATE(pwm_3);

DRV_PWM_INIT(pwm[0]);
DRV_PWM_INIT(pwm[1]);
DRV_PWM_INIT(pwm[2]);
DRV_PWM_INIT(pwm[3]);
```

3. Set start_time.

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```
period = 10; // 10us
duty_percent = 30; //30%, duration high 3us per 10us
DRV_PWM_START(pwm[0], period, duty_percent, PWM_DRV_MODE_US); //PWM Start

period = 20; // 20us
duty_percent = 40; //40%, duration high 8us per 10us
DRV_PWM_START(pwm[1], period, duty_percent, PWM_DRV_MODE_US); //PWM Start

period = 40; // 40us
duty_percent = 50; //50%, duration high 20us per 10us
DRV_PWM_START(pwm[2], period, duty_percent, PWM_DRV_MODE_US); //PWM Start

period = 80; // 80us
duty_percent = 80; //80%, duration high 64us per 10us
DRV_PWM_START(pwm[3], period, duty_percent, PWM_DRV_MODE_US); //PWM Start
```

4. Set start_cycle.

```
// 2400 cycles(=30us @ 80 MHz), cycle = value + 1
cycle = 2400-1;
// 1680 cycles(=21us@80 MHz, 70% Duty High), duty_cycle = value + 1
duty_cycle = 1680-1;
DRV_PWM_START(pwm[0], cycle, duty_cycle, PWM_DRV_MODE_CYC); //PWM Start

// 2400 cycles(=30us @ 80 MHz), cycle = value + 1
cycle = 2400-1;
// 1680 cycles(=21us@ 80 MHz, 70% Duty High), 70% Duty High), duty_cycle =
value + 1
duty_cycle = 1680-1;
DRV_PWM_START(pwm[1], cycle, duty_cycle, PWM_DRV_MODE_CYC); //PWM Start

// 2400 cycles(=30us @ 80 MHz), cycle = value + 1
cycle = 2400-1;
// 1680 cycles(=21us@ 80 MHz, 70% Duty High), 70% Duty High), duty_cycle =
value + 1
duty_cycle = 1680-1;
DRV_PWM_START(pwm[2], cycle, duty_cycle, PWM_DRV_MODE_CYC); //PWM Start

// 2400 cycles(=30us @ 80 MHz), cycle = value + 1
cycle = 2400-1;
// 1680 cycles(=21us@ 80 MHz, 70% Duty High), 70% Duty High), duty_cycle =
value + 1
duty_cycle = 1680-1;
DRV_PWM_START(pwm[3], cycle, duty_cycle, PWM_DRV_MODE_CYC); //PWM Start
```

5. Stop PWM.

```
DRV_PWM_STOP(pwm[0], 0);
DRV_PWM_STOP(pwm[1], 0);
DRV_PWM_STOP(pwm[2], 0);
DRV_PWM_STOP(pwm[3], 0);
```

16.7 ADC

This section shows how to use the ADC interface.

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16.7.1 Introduction

The DA16200/DA16600 has Analog-to-Digital Converters (ADC): a four-channel single-end ADC of 12-bit resolution. Analog input is measured by means of 4 pins from GPIO0 to GPIO3, and the pin selection is changed through the register setting. See Figure 111 and Table 66.

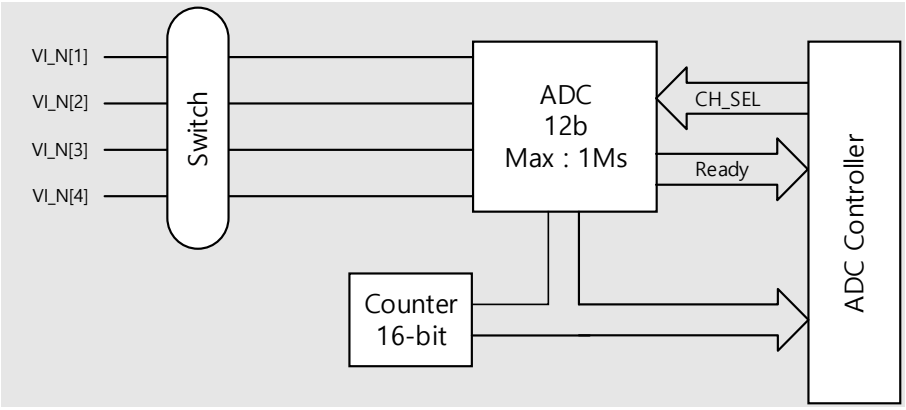

Figure 111: ADC Control Block Diagram

Table 66: AUX ADC Pin Configuration

Pin Name	Pin Number		I/O	Function Name
	QFN	fcCSP		
GPIOA3	36	D4	A	Analog signal
GPIOA2	37	B2	A	Analog signal
GPIOA1	38	C3	A	Analog signal
GPIOA0	39	A3	A	Analog signal

For more details, see the datasheet Ref. [2].

16.7.2 API

Table 67: APIs for ADC Interface

Item		Description
HANDLE DRV_ADC_CREATE(UINT32 dev_id)		
Parameter	dev_id	Device number to create a handle
Return		If succeeded, return handle for such device. If failed, return NULL.
Description		Function create handle with parameter dev_id designated
int DRV_ADC_INIT(HANDLE handler, unsigned int use_timestamp)		
Parameter	handler	Device handle to initialize
Return		If succeeded, return TRUE. If failed, return FALSE.
Description		ADC Initialization command
Int DRV_ADC_IOCTL(HANDLE handler, UINT32 cmd, VOID *data)		
Parameter	handler	N/A
	cmd	N/A
	data	N/A
Return		N/A

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Item		Description
Description		ADC IOCTL command
int DRV_ADC_START(HANDLE handler, UINT32 divider12, UINT32 dummy)		
Parameter	handler	Device handle to start
	divider12	Fs = sys_clk / 15 / (div12 +1)
Return		If succeeded, return TRUE. If failed, return FALSE.
Description		ADC start command
int DRV_ADC_STOP(HANDLE handler, UINT32 dummy)		
Parameter	handler	Device handle to stop
Return		If succeeded, return TRUE. If failed, return FALSE.
Description		ADC stop command
Int DRV_ADC_CLOSE(HANDLE handler)		
Parameter	handler	Device handle to close
Return		If succeeded, return TRUE. If failed, return FALSE.
Description		ADC driver close
int DRV_ADC_READ(HANDLE handler, UINT32 channel, UINT32 *data, UINT32 dummy)		
Parameter	handler	Device handle to read
	channel	Channel number to read instant ADC value
	*data	Buffer to read
Return		If succeeded, return TRUE. If failed, return FALSE.
Description		ADC read command
int DRV_ADC_READ_DMA(HANDLE handler, UINT32 channel, UINT16 *p_data, UINT32 p_dlen, UINT32 dummy)		
Parameter	handler	Device handle to read with specified length
	channel	Channel number to read
	*p_data	Buffer block to read
	p_dlen	Number of samples to read with DMA, not buffer length
Return		If succeeded, return TRUE. If failed, return FALSE.
Description		ADC read commands through DMA
int DRV_ADC_ENABLE_CHANNEL(HANDLE handler, UINT32 channel, unsigned int sel_adc, UINT32 dummy)		
Parameter	handler	Device handle
	channel	Channel number to set ADC devices
	sel_adc	12: SMI 12B ADC, 0: disable
Return		If succeeded, return TRUE. If failed, return FALSE.
Description		ADC channel enables command
int DRV_ADC_SET_INTERRUPT(HANDLE handler, UINT32 channel, UINT32 enable, UINT32 type, UINT32 dummy)		
Parameter	handler	Device handle
	channel	Channel number to set interrupt
	enable	1: enable interrupt, 0: disable interrupt

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Item		Description
	type	ADC_INTERRUPT_FIFO_HALF (0) ADC_INTERRUPT_FIFO_FULL (1) ADC_INTERRUPT_THD_OVER (2) ADC_INTERRUPT_THD_UNDER (3) ADC_INTERRUPT_THD_DIFF (4) ADC_INTERRUPT_ALL (0xf)
Return		If succeeded, return TRUE. If failed, return FALSE.
Description		ADC interrupt set command
int DRV_ADC_SET_THD_VALUE(HANDLE handler, UINT32 type, UINT32 enable, UINT32 thd, UINT32 dummy);		
Parameter	handler	Device handle
	type	ADC_THRESHOLD_TYPE_12B_OVER (0) ADC_THRESHOLD_TYPE_12B_UNDER (2) ADC_THRESHOLD_TYPE_12B_DIFF (4)
	thd	Interrupt threshold. 0 ~ 65535 range. Upper 12 bits of 16-bit data are valid values.
Return		If succeeded, return TRUE. If failed, return FALSE.
Description		ADC interrupt threshold set command
int DRV_ADC_WAIT_INTERRUPT(HANDLE handler, UNSIGNED *mask_evt);v		
Parameter	handler	Device handle
	*mask_evt	Mask for waiting interrupt bit[19] : Interrupt status for Threshold Difference of CHANNEL 3 bit[18] : Interrupt status for Threshold Difference of CHANNEL 2 bit[17] : Interrupt status for Threshold Difference of CHANNEL 1 bit[16] : Interrupt status for Threshold Difference of CHANNEL 0 bit[15] : Interrupt status for Threshold Under level of CHANNEL 3 bit[14] : Interrupt status for Threshold Under level of CHANNEL 2 bit[13] : Interrupt status for Threshold Under level of CHANNEL 1 bit[12] : Interrupt status for Threshold Under level of CHANNEL 0 bit[11] : Interrupt status for Threshold Over level of CHANNEL 3 bit[10] : Interrupt status for Threshold Over level of CHANNEL 2 bit[9] : Interrupt status for Threshold Over level of CHANNEL 1 bit[8] : Interrupt status for Threshold Over level of CHANNEL 0 bit[7] : Interrupt status for full level of CHANNEL 3 bit[6] : Interrupt status for full level of CHANNEL 2 bit[5] : Interrupt status for full level of CHANNEL 1 bit[4] : Interrupt status for full level of CHANNEL 0 bit[3] : Interrupt status for half level of CHANNEL 3 bit[2] : Interrupt status for half level of CHANNEL 2 bit[1] : Interrupt status for half level of CHANNEL 1 bit[0] : Interrupt status for half level of CHANNEL 0
Return		If succeeded, return masked interrupt. If failed, return FALSE.
Description		Wait ADC interrupt

16.7.3 Interrupt Description

ADC_INTERRUPT_FIFO_HALF: this interrupt occurs when the FIFO Level is 4 or later.

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ADC_INTERRUPT_FIFO_FULL: this interrupt occurs when FIFO Level is 8.

ADC_INTERRUPT_THD_OVER: this interrupt occurs when the current input value to the ADC device is greater than the value set in the "ADC_THRESHOLD_TYPE_12B_OVER" type.

ADC_INTERRUPT_THD_UNDER: this interrupt occurs when the current input value to the ADC device is smaller than the value set in the " ADC_THRESHOLD_TYPE_12B_UNDER " type.

ADC_INTERRUPT_THD_DIFF: this interrupt occurs when the difference between the current input value to the ADC device and the previously input value is greater than the value set in "ADC_INTERRUPT_THD_DIFF" type.

16.7.4 How to Run

1. In the e²studio, import a project for the ADC sample application as follows:
   - *~/SDK/apps/common/examples/Peripheral/ADC/projects/da16200*
2. There are three types of preprocessor statements defined in the ADC example code.
   - ADC_SAMPLE_READ
     - Read and print ADC input values
   - ADC_SAMPLE_INTERRUPT
     - Set the interrupt to occur at 0.7 V or less and verify that the setting works
   - ADC_SAMPLE_DPM
     - Set the ADC value of 0.15 V or more before entering Sleep Mode 2, and it wakes up from Sleep mode 2 when ADC input is 0.15 V or more.
3. Build the DA16200 SDK, download the RTOS image to the DA16200 EVB, and reboot.
4. The sample application code is written in the following source file:
   ~/SDK/apps/common/examples/Peripheral/ADC/src/adc_sample.c

16.7.5 Sample Code – SAMPLE_READ

16.7.5.1 Test Procedure

1. Provide 0~1.3 V to P7 ~ P9, in connector J4.
2. Run the ADC example and read the ADC value.
3. Compare the value with the voltage supplied.

16.7.5.2 Sample Code for Reading ADC

1. Initialize ADC.

```
PRINTF("ADC_SAMPLE\n");
DA16X_CLOCK_SCGATE->Off_DAPB_AuxA = 0;
DA16X_CLOCK_SCGATE->Off_DAPB_APBS = 0;

// Set PAD Mux. GPIO_0 (ADC_CH0), GPIO_1(ADC_CH1)
_da16x_io_pinmux(PIN_AMUX, AMUX_AD12);

// Create Handle
hadc = DRV_ADC_CREATE(DA16200_ADC_DEVICE_ID);

// Initialization
DRV_ADC_INIT(hadc, DA16x_ADC_NO_TIMESTAMP);
```

2. Start ADC.

```
// Start. Set Sampling Frequency. 12B ADC Set to 200 kHz
// Clock = 1 MHZ / (value + 1)
```

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```
// Ex) If Value = 4, Clock = 1 MHz / (4+1) = 200 kHz
DRV_ADC_START(hadc, DA16x_ADC_DIVIDER_12, 0);
```

3. Enable ADC.

```
// Set ADC_0 to 12Bit ADC, ADC_1 to 12Bit ADC
DRV_ADC_ENABLE_CHANNEL(hadc, DA16200_ADC_CH_0, DA16x_ADC_SEL_ADC_12, 0);
DRV_ADC_ENABLE_CHANNEL(hadc, DA16200_ADC_CH_1, DA16x_ADC_SEL_ADC_12, 0);
```

4. Read ADC Using DMA.

```
// Read 16ea ADC_0 Value. 12B ADC, Bit [15:4] is valid adc_data, [3:0] is zero
DRV_ADC_READ_DMA(hadc, DA16200_ADC_CH_0, data0, DA16x_ADC_NUM_READ * 2,
              DA16x_ADC_TIMEOUT_DMA, 0);

// Read 16ea ADC_1 Value
DRV_ADC_READ_DMA(hadc, DA16200_ADC_CH_1, data1, DA16x_ADC_NUM_READ * 2,
              DA16x_ADC_TIMEOUT_DMA, 0);
```

5. Read ADC.

```
// Read Current ADC_0 Value. Caution!! When read current adc value consequently,
// need delay at each read function bigger than Sampling Frequency
DRV_ADC_READ(hadc, DA16200_ADC_CH_0, &data, 0);
```

6. Close ADC.

```
// Close ADC
DRV_ADC_CLOSE(hadc);
0.
```

16.7.6 Sample Code - ADC_SAMPLE_INTERRUPT

16.7.6.1 Test Procedure

1. Provide 1.3 voltage to P7 ~ P9, in connector J4.
2. Run the ADC example.
3. Change the power supply to the ADC to 0.7 V or lower to see if an interrupt occurs.

16.7.6.2 Sample Code for ADC Interrupt

1. Initialize ADC.

```
HANDLE hadc;
int status, int_handling_mode;
unsigned int data, type, thd;

PRINTF("ADC_SAMPLE\n");
DA16X_CLOCK_SCGATE->Off_DAPB_AuxA = 0;
DA16X_CLOCK_SCGATE->Off_DAPB_APBS = 0;

// Set PAD Mux. GPIO_0 (ADC_CH0), GPIO_1(ADC_CH1)
_da16x_io_pinmux(PIN_AMUX, AMUX_AD12);

// Create Handle
hadc = DRV_ADC_CREATE(DA16200_ADC_DEVICE_ID);

// Initialization
status = DRV_ADC_INIT(hadc, DA16x_ADC_NO_TIMESTAMP);
PRINTF("ADC-INIT: %d\n", status);
```

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2. Start ADC.

```
// Start. Set Sampling Frequency. 12B ADC Set to 200 kHz
// Clock = 1 MHZ / (value + 1)
// Ex) If Value = 4, Clock = 1 MHz / (4+1) = 200 kHz
status = DRV_ADC_START(hadc, DA16x_ADC_DIVIDER_12, 0);
RINTF("ADC start: %d\n", status);

// Set ADC_0 to 12Bit ADC
status = DRV_ADC_ENABLE_CHANNEL(hadc, DA16200_ADC_CH_0, DA16x_ADC_SEL_ADC_12, 0);
PRINTF("ADC enable: %d\n", status);

//Set Data type offset binary, 0 : 2's complement ,  1 : offset binary
type = 1;
DRV_ADC_IOCTL(hadc, ADC_SET_DATA_MODE, &type);
```

3. Read ADC.

```
// Read Current ADC_0 Value. Caution!! When read current adc value consequently,
need delay at each read function bigger than Sampling Frequency
DRV_ADC_READ(hadc, DA16200_ADC_CH_0, &data, 0);
PRINTF("Current ADC Value = 0x%x\r\n", GET_VALID_ADC_VALUE(data));
```

4. Set ADC Interrupt.

```
//set threshold
//value 0x800(=0.7V/1.4V * 4095), max=4095(1.4V), min=0(0V), increase linearly)
means about 0.7Volt in EVK environment.
thd = 0x800;
//thd value must be shifted 4 bits right.
status = DRV_ADC_SET_THD_VALUE(hadc, ADC_THRESHOLD_TYPE_12B_UNDER,
CONVERT_TO_THD_VALUE(thd), 0);
PRINTF("ADC-set threshold: %d\n", status);

// set Interrupt
status = DRV_ADC_SET_INTERRUPT(hadc, DA16200_ADC_CH_0, TRUE,
ADC_INTERRUPT_THD_UNDER, 0);
PRINTF("ADC-set interrupt: %d\n", status);

//set Interrupt Handling Mode
//ADC_INTERRUPT_MODE_EVENT mode : in interrupt handler, call set_event function.
//ADC_INTERRUPT_MODE_MASK mode  : in interrupt handler, disable interrupt.
int_handling_mode = ADC_INTERRUPT_MODE_EVENT | ADC_INTERRUPT_MODE_MASK;
DRV_ADC_IOCTL(hadc, ADC_SET_INTERRUPT_MODE, (void *)(&int_handling_mode));
```

5. Wait ADC Interrupt.

```
//Wait Interrupt
UNSIGNED interrupt_status ;
DRV_ADC_WAIT_INTERRUPT(hadc, &interrupt_status);

vTaskDelay(5);
```

6. Print and Disable Interrupt.

```
// disable Interrupt
status = DRV_ADC_SET_INTERRUPT(hadc, DA16200_ADC_CH_0, FALSE,
ADC_INTERRUPT_THD_UNDER, 0);
PRINTF("ADC-reset interrupt: %d\n", status);

// Read Current ADC_0 Value. Caution!! When read current adc value consequently,
need delay at each read function bigger than Sampling Frequency
DRV_ADC_READ(hadc, DA16200_ADC_CH_0, &data, 0);
```

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```
PRINTF("Interrupt Occured with Value = 0x%x\r\n", GET_VALID_ADC_VALUE(data));

vTaskDelete(NULL);
```

16.7.7 Sample Code - ADC_SAMPLE_DPM

16.7.7.1 Test Procedure

1. Provide 0 V to P7 ~ P9, in connector J4.
2. Run the ADC example.
3. After the DA16200 enters sleep mode, verify that it wakes up by changing the voltage supplied to the ADC to at least 0.15 V.

16.7.7.2 Sample Code for Wake Up DPM

1. Initialize ADC.

```
HANDLE hadc;
int status, int_handling_mode;
unsigned int data, type, val;
unsigned long long  wakeup_time;
UINT32 wakeup_src;

DA16X_CLOCK_SCGATE->Off_DAPB_AuxA = 0;
DA16X_CLOCK_SCGATE->Off_DAPB_APBS = 0;

// Set PAD Mux. GPIO_0 (ADC_CH0), GPIO_1(ADC_CH1)
_da16x_io_pinmux(PIN_AMUX, AMUX_AD12);

// Create Handle
hadc = DRV_ADC_CREATE(DA16200_ADC_DEVICE_ID);

// Initialization
status = DRV_ADC_INIT(hadc, DA16200_ADC_NO_TIMESTAMP);
//PRINTF("ADC-INIT: %d\n",status);
```

2. Start ADC.

```
// Start. Set Sampling Frequency. 12B ADC Set to 200 kHz
// Clock = 1 MHZ / (value + 1)
// Ex) If Value = 4, Clock = 1 MHz / (4+1) = 200 kHz
status = DRV_ADC_START(hadc, DA16200_ADC_DIVIDER_12, 0);
//PRINTF("ADC start: %d\n",status);

// Set ADC_0 to 12Bit ADC
status = DRV_ADC_ENABLE_CHANNEL(hadc, DA16200_ADC_CH_0,
DA16200_ADC_SEL_ADC_12, 0);
//PRINTF("ADC enable: %d\n",status);

//Set Data type offset binary, 0 : 2's complement ,  1 : offset binary
type = 1;
DRV_ADC_IOCTL(hadc, ADC_SET_DATA_MODE, &type);
```

3. Read ADC.

```
//Read Current ADC_0 Value.
DRV_ADC_READ(hadc, DA16200_ADC_CH_0, &data, 0);
PRINTF("Current ADC Value = 0x%x\r\n", data & 0xffff);
```

4. Set ADC Interrupt.

```
//set threshold
```

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```
//value 0x8000 means about 0.7Volt in EVK environment.
status = DRV_ADC_SET_THD_VALUE(hadc, ADC_THRESHOLD_TYPE_12B_OVER, 0x1B60,
          0);
PRINTF("ADC-set threshold: %d\n", status);

//set Interrupt
status = DRV_ADC_SET_INTERRUPT(hadc, DA16200_ADC_CH_0, TRUE,
ADC_INTERRUPT_THD_OVER, 0);
PRINTF("ADC-set interrupt: %d\n", status);

//set Interrupt Mode
int_handling_mode = ADC_INTERRUPT_MODE_EVENT | ADC_INTERRUPT_MODE_MASK;
DRV_ADC_IOCTL(hadc, ADC_SET_INTERRUPT_MODE, (void*) (&int_handling_mode));

//Set ADC for Sleep 2 //
DRV_ADC_SET_THRESHOLD(hadc, DA16200_ADC_CH_0, 0x1B6,
ADC_RTC_THRESHOLD_TYPE_OVER);
val = 1;
DRV_ADC_IOCTL(hadc, ADC_SET_RTC_CYCLE_BEFORE_ON, &val);
val = 1;
DRV_ADC_IOCTL(hadc, ADC_SET_RTC_CYCLE_BEFORE_CAPTURE, &val);
val = 0;
DRV_ADC_IOCTL(hadc, ADC_SET_CAPTURE_STEP, &val);
DRV_ADC_SET_SLEEP_MODE(hadc, 1, 0xf, 1);
DRV_ADC_SET_RTC_ENABLE_CHANNEL(hadc, DA16200_ADC_CH_0, 1);

drv_adc_sensor_out_enable(hadc);
vTaskDelay(50);
```

5. Enter Sleep Mode 2.

```
wakeup_src = da16x_boot_get_wakeupmode();
PRINTF("\nWakeup source is 0x%x\n", wakeup_src);

wakeup_time = 10000000000 * 1000000;
start_dpm_sleep_mode_2(wakeup_time, TRUE);
PRINTF("Sample: Go to sleep 2 ... \n");
```

16.8 SPI

This section shows how the SPI loopback operation works.

16.8.1 Introduction

16.8.1.1 SPI Master

The SPI master communicates in full duplex mode that uses a master-slave architecture with a single master. The master device originates the frame to be read or written. Multiple slave-devices are supported with the selection of individual chip select (CS) lines.

Table 68 shows the pin definition of the SPI master interface. To use as an SPI master, the CSB signal can be used with any of the GPIO pins. CSB [3:2] can be selected from the GPIO special function. This is done through register settings in the GPIO.

Table 68: SPI Master Pin Configuration

Pin Name	Pin Number		I/O	Function Name
	QFN	fcCSP		
GPIOx			O	E_SPI_CSB[3:1]

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Pin Name	Pin Number		I/O	Function Name
	QFN	fcCSP		
GPIOA6	32	E3	O	E_SPI_CSB[0]
GPIOA7	31	E1	O	E_SPI_CLK
GPIOA8	30	G3	I/O	E_SPI_MOSI or E_SPI_D[0]
GPIOA9	29	H2	I/O	E_SPI_MISO or E_SPI_D[1]
GPIOA10	28	F2	I/O	E_SPI_D[2]
GPIOA11	27	G1	I/O	E_SPI_D[3]

16.8.1.2 SPI Slave

The SPI slave interface enables support to control the DA16200/DA16600 from an external host. The range of the SPI clock speed is the same as that of the internal bus clock speed. The SPI slave supports both burst mode and non-burst mode. In the burst mode, SPI_CSB remains active from the start to the end of communication. In the non-burst mode, SPI_CLK remains active at every 8-bit.

The communication protocols of the SPI slave interface use either 4-byte or 8-byte control signals. Between the two available communication protocols, the CPU chooses one before initiating the control.

Table 69: SPI Slave Pin Configuration

Pin Name	Pin Number		I/O	Function Name
	QFN	fcCSP		
GPIOA2	37	B2	I	SPI_CSB
GPIOA6	32	E3	I	
GPIOA3	36	D4	I	SPI_CLK
GPIOA7	31	E1	I	
GPIOA1	38	C3	I	SPI_MOSI
GPIOA9	29	H2	I	
GPIOA11	27	G1	I	
GPIOA0	39	A3	O	SPI_MISO
GPIOA8	30	G3	O	
GPIOA10	28	F2	O	

16.8.2 API

Table 70: APIs for SPI Master Interface

Item		Description
HANDLE SPI_CREATE(UINT32 dev_id)		
Parameter	dev_id	Instance Number of SPI (UINT32))
Return		Handler of SPI Driver (HANDLE)
Description		Returns the SPI Handler that is defined in "spi.h" file ● create the GPIO handler for chip selection

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Item		Description
int SPI_INIT (HANDLE handler)		
Parameter	Handler	SPI Driver (HANDLE)
Return		TRUE / FALSE (int)
Description		Initializes the SPI Handler to set up GPIO and activate the ISR ● create the MUTEX for support to control multi-slaves
int SPI_IOCTL(HANDLE handler, UINT32 cmd, VOID *data)		
Parameter	Handler	SPI Driver (HANDLE)
	Cmd	IOCTL command
	data	IOCTL parameters
Return		TRUE / FALSE (int)
int SPI_WRITE(HANDLE handler, void *pdata, UINT32 dlen)		
Parameter	Handler	SPI Driver (HANDLE)
Return		zero - false, non-zero - data length (int)
Description		SPI write operation ● pdata: TX data buffer ● dlen: byte length
int SPI_WRITE_READ(HANDLE handler, void *snddata, UINT32 sndlen, void *rcvdata, UINT32 rcvlen)		
Parameter	Handler	SPI Driver (HANDLE)
Return		zero - false, non-zero - data length (int)
Description		SPI write and read operation (write before read) This function will run in concatenation mode internally ● snddata: TX data buffer ● sndlen: byte length ● rcvdata: TX data buffer rcvlen: byte length
Int SPI_TRANSMIT(HANDLE handler, VOID *snddata, UINT32 sndlen, VOID *rcvdata, UINT32 rcvlen)		
Parameter	Handler	SPI Driver (HANDLE)
Return		zero - false, non-zero - data length (int)
Description		Basic operation running once in SPI burst mode (send before receiving) This function does not support to change a bus mode automatically ● snddata: TX data buffer ● sndlen: byte length ● rcvdata: TX data buffer rcvlen: byte length
Int SPI_CLOSE(HANDLE handler)		
Parameter	Handler	SPI Driver (HANDLE)
Return		TRUE / FALSE (int)
Description		Release the SPI handler

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Table 71: APIs for SPI Slave Interface

void host_spi_slave_init(void)
Change Slave I/F to SPI protocol. Enable clock to SPI slave device and GPIO Interrupt Set
void host_i2c_slave_init(void)
Change Slave I/F to I2C protocol. Enable clock to I2C slave device and GPIO Interrupt Set

16.8.3 How to Run

1. In the e²studio, import a project for the SPI sample application as follows:
   - *~/SDK/apps/common/examples/Peripheral/SPI/projects/da16200*
2. Connect the SPI master pins and SPI slave pins.
   - GPIOA[0] (SPI_MISO) - GPIOA[9] (E_SPI_DIO1)
   - GPIOA[1] (SPI_MOSI) - GPIOA[8] (E_SPI_DIO0)
   - GPIOA[2] (SPI_CSB) - GPIOA[6] (E_SPI_CSB)
   - GPIOA[3] (SPI_CLK) - GPIOA[7] (E_SPI_CLK)
3. Build the DA16200 SDK, download the RTOS image to the DA16200 EVB, and reboot.
4. The SPI loopback communication works as shown in Figure 112.

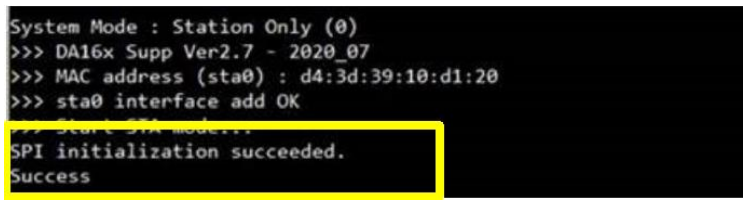

Figure 112: SPI Loopback Communication

16.8.4 Sample Code

1. Create an SPI handle and configure the interface.

```
spi = SPI_CREATE(SPI_UNIT_0);
if(spi == NULL) {
    PRINTF("[%s]failed to create instance\n", __func__);
    return;
}

_sys_clock_read( ioctldata, sizeof(UINT32));
SPI_IOCTL(spi, SPI_SET_CORECLOCK, ioctldata);

/* set SPI speed */
ioctldata[0] = SMC_SPI_SPEED * MHz;
SPI_IOCTL(spi, SPI_SET_SPEED, ioctldata);

/* set SPI polarity */
ioctldata[0] = SMC_SPI_POLARITY;
SPI_IOCTL(spi, SPI_SET_FORMAT, ioctldata);

/* set SPI DMA config */
ioctldata[0] = SPI_DMA_MP0_BST(8)
             | SPI_DMA_MP0_IDLE(1)
             | SPI_DMA_MP0_HSIZE(XHSIZE_DWORD)
```

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```
                | SPI_DMA_MP0_AI(SPI_ADDR_INCR);
SPI_IOCTL(spi, SPI_SET_DMA_CFG, ioctldata);
SPI_IOCTL(spi, SPI_SET_DMAMODE, NULL);

/* set SPI chip select, io operation type */
ioctldata[0] = SMC_SPI_CS;
ioctldata[1] = SMC_IO_OPERTATION_TYPE;
SPI_IOCTL( spi, SPI_SET_WIRE, (VOID *)ioctldata);

/* set SPI delay index */
ioctldata[0] = SPI_DELAY_INDEX_LOW;
SPI_IOCTL(spi, SPI_SET_DELAY_INDEX, ioctldata);

/* SPI initialization */
status = SPI_INIT(spi);
```

2. Set pin multiplexing as SPI master and SPI slave.

```
/* pinmux config for SPI Slave - GPIOA[3:0] */
_da16x_io_pinmux(PIN_AMUX, AMUX_SPIs);
_da16x_io_pinmux(PIN_BMUX, BMUX_SPIs);

/* pinmux config for SPI Host  - GPIOA[9:6] */
_da16x_io_pinmux(PIN_DMUX, DMUX_SPIm);
_da16x_io_pinmux(PIN_EMUX, EMUX_SPIm);
```

3. Write data.

```
/* generate host interface protocol header */
_buf[0] = (addr >> 8) & 0xff;
_buf[1] = (addr >> 0) & 0xff;
_buf[2] = (HPC_WRITE_CMD & 0xff)
        | (HPC_COMMON_ADDR_MODE << 5)
        | (HPC_REF_LEN<<4)|((length>>8)&0xf);
_buf[3] = (length)&0xff;

/* copy data to buf */
memcpy(&(_buf[4]), data, length);

/* Bus Lock : CSEL0 */
ioctldata[0] = TRUE;
ioctldata[1] = portMAX_DELAY;
ioctldata[2] = SPI_CSEL_0;
SPI_IOCTL(spi, SPI_SET_LOCK, (VOID *)ioctldata);

status = SPI_WRITE(spi, _buf, (HPC_HEADER_LEN + length));

/* Bus Unlock */
ioctldata[0] = FALSE;
ioctldata[1] = portMAX_DELAY;
ioctldata[2] = SPI_CSEL_0;
SPI_IOCTL(spi, SPI_SET_LOCK, (VOID *)ioctldata);
```

4. Read data.

```
_buf[0] = (addr >> 8) & 0xff;
_buf[1] = (addr >> 0) & 0xff;
_buf[2] = HPC_READ_CMD
        | (HPC_COMMON_ADDR_MODE << 5)
        | (HPC_REF_LEN<<4)|((len>>8)&0xf);
_buf[3] = (len)&0xff;
```

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```
/* Bus Lock : CSEL0 */
ioctldata[0] = TRUE;
ioctldata[1] = portMAX_DELAY;
ioctldata[2] = SPI_CSEL_0;
SPI_IOCTL(spi, SPI_SET_LOCK, (VOID *)ioctldata);

status = SPI_WRITE_READ(spi, _buf, 4, rx_data, len);

/* Bus Unlock */
ioctldata[0] = FALSE;
ioctldata[1] = portMAX_DELAY;
ioctldata[2] = SPI_CSEL_0;
SPI_IOCTL(spi, SPI_SET_LOCK, (VOID *)ioctldata);
```

16.9 SDIO

The DA16200 can be accessed with the SDIO interface. If the user wants to test it, then another host system is needed.

16.9.1 Introduction

16.9.1.1 SDIO Master

Secure Digital Input Output (SDIO) is a full/high speed card suitable for memory card and I/O card applications with low power consumption. The full/high speed card supports SPI, 1-bit SD and 4-bit SD transfer modes at the full clock range of 0~50 MHz. To be compatible with the serviceable SDIO clock, the internal BUS clock should be set to a minimum of 50 MHz. The CIS and CSA areas are inside the internal memory, and the SDIO registers (CCCR and FBR) are programmed by the SD host.

For more details, see the datasheet, Ref. [2].

16.9.1.2 SDIO Slave

The GPIO4 and GPIO5 pins are set to SDIO CMD and CLK by default. If SDIO initialization is done and SDIO communication is enabled, then the SDIO data pin setting is done automatically. In other words, when the SDIO communication is detected, the pin used as the SDIO data among the GPIO pins is automatically activated in the SDIO use mode. However, the auto setting function is not supported for the F_xx pin used as the flash function.

16.9.2 API

Table 72: APIs for SDIO Master Interface

Item		Description
HANDLE EMMC_CREATE(void);		
Parameter	None	
Return		If succeeded, return handle for such device. If failed, return NULL.
Description		Create EMMC handle.
int EMMC_INIT(HANDLE handler)		
Parameter	handler	Device handle
Return		If succeeded, return ERR_NONE. If failed, return ERR_MMC_INIT.
Description		Initialize the SD/eMMC or SDIO card.
int EMMC_CLOSE(HANDLE handler)		
Parameter	handler	Device handle

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Item		Description
Return		If succeeded, return ERR_NONE.
int SDIO_ENABLE_FUNC(HANDLE handler, UINT32 func_num)		
Parameter	handler	Device handle
	func_num	Function number to enable
Return		If succeeded, return ERR_NONE.
int SDIO_DISABLE_FUNC(HANDLE handler, UINT32 func_num)		
Parameter	handler	Device handle
	func_num	Function number to disable
Return		If succeeded, return ERR_NONE.
int SDIO_SET_BLOCK_SIZE(HANDLE handler, UINT32 func_num, UINT32 blk_size)		
Parameter	handler	Device handle
	func_num	Function number
	blk_size	Block size
Return		If succeeded, return ERR_NONE.
int SDIO_READ_BYTE(HANDLE handler, UINT32 func_num, UINT32 addr, UINT8 *data)		
Parameter	handler	Device handle
	func_num	Function number
	addr	Address in the function
	data	Data pointer
Return		If succeeded, return ERR_NONE. And byte data is stored in data.
int SDIO_WRITE_BYTE(HANDLE handler, UINT32 func_num, UINT32 addr, UINT8 *data)		
Parameter	handler	Device handle
	func_num	Function number
	addr	Address in the function
	data	Data pointer
Return		If succeeded, return ERR_NONE.
int SDIO_READ_BURST(HANDLE handler, UINT32 func_num, UINT32 addr, UINT32 incr_addr, UINT8 *data, UINT32 count, UINT32 blksz)		
Parameter	handler	Device handle
	func_num	Function number
	addr	Function address
	Incr_addr	Increase address option (1: address increase, 0: address fix)
	data	Data pointer
	count	Count of blocks
	blksz	Block size
Return		If succeeded, return ERR_NONE. If failed, Error Code return, see also EMMC.h.
int SDIO_WRITE_BURST(HANDLE handler, UINT32 func_num, UINT32 addr, UINT32 incr_addr, UINT8 *data, UINT32 count, UINT32 blksz)		
Parameter	handler	Device handle

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Item		Description
	func_num	Function number
	addr	Function address
	Incr_addr	Increase address option (1: address increase, 0: address fix)
	data	Data pointer
	count	Count of blocks
	blksz	Block size
Return		If succeeded, return ERR_NONE.

Table 73: SDIO Slave Pin Configuration

Pin Name	Pin Number		I/O	Function Name
	QFN	fcCSP		
GPIOA4	34	F4	I/O	SDIO_CMD
F_CSN	18	J5	I/O	
GPIOA5	33	D2	I	SDIO_CLK
F_CLK	19	K4	I	
GPIOA9	29	H2	I/O	SDIO_D0
F_IO0	14	K8	I/O	
GPIOA8	30	G3	I/O	SDIO_D1
F_IO1	15	L7	I/O	
GPIOA7	31	E1	I/O	SDIO_D2
F_IO2	16	J7	I/O	
GPIOA6	32	E3	I/O	SDIO_D3
F_IO3	17	K6	I/O	

For more details, see the datasheet, Ref. [2].

16.9.3 How to Run

1. In the e²studio, import a project for the SDIO sample application as follows:
   - *~/SDK/apps/common/examples/Peripheral/SDIO/projects/da16200*
2. The sample application code is written in the following source file:
   ~/SDK/apps/common/examples/Peripheral/SDIO/src/sdio_sample.c
   - GPIOA[9:4] needs to connect to the HOST system
   - GPIOA[9] - SDIO_D0, GPIOA[8] - SDIO_D1
   - GPIOA[7] - SDIO_D2, GPIOA[6] - SDIO_D3
   - GPIOA[5] - SDIO_CLK, GPIOA[4] - SDIO_CMD
3. Build the DA16200 SDK, download the RTOS image to the DA16200 EVB, and reboot.
4. The sample runs as soon as the boot up is completed.

```
[/DA16200]  # sdio_slave start
 Now the sdio host can access the DA16200
[/DA16200] #
```

Now the DA16200 is ready to receive an SDIO command.

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16.9.4 Sample Code

In DA16200, the loopback test between SD host and sdio_slave is not supported. Instead, in the sample code provided, SDIO is just waiting for a request from the host after initialization.

```
/*
 * SDIO Slave
 */
// GPIO[9] - SDIO_D0,  GPIO[8] - SDIO_D1
_da16x_io_pinmux(PIN_EMUX, EMUX_SDs);
// GPIO[5] - SDIO_CLK,  GPIO[4] - SDIO_CMD
_da16x_io_pinmux(PIN_CMUX, CMUX_SDs);
// GPIO[7] - SDIO_D2,  GPIO[6] - SDIO_D3
_da16x_io_pinmux(PIN_DMUX, DMUX_SDs);

// clock enable sdio_slave
DA16X_CLOCK_SCGATE->Off_SSI_M3X1 = 0;
DA16X_CLOCK_SCGATE->Off_SSI_SDIO = 0;

SDIO_SLAVE_INIT();
/* now the sdio host can access the DA16200 */
Printf("now the sdio host can access the DA16200\r\n");
```

16.10 SD/eMMC

This section shows how to use the SD/eMMC interface.

16.10.1 Introduction

The SD/eMMC host interface of the DA16200/DA16600 provides access to SD or eMMC cards. The SD/eMMC host interface supports a 4-bit data bus with a maximum clock rate of 48 MHz giving a maximum data rate of 24 MB/s (192 Mbps). The SD/eMMC pin mux condition is defined in Table 74.

Table 74: SD/eMMC Master Pin Configuration

Pin Name	Pin Number		I/O	Function Name
	QFN	fcCSP		
GPIOA4	34	F4	I/O	SD/eMMC_CMD
GPIOA5	33	D2	O	SD/eMMC_CLK
GPIOA9	29	H2	I/O	SD/eMMC_D0
GPIOA8	30	G3	I/O	SD/eMMC_D1
GPIOA7	31	E1	I/O	SD/eMMC_D2
GPIOA6	32	E3	I/O	SD/eMMC_D3
GPIOA10	28	F2	I	SD/eMMC_WRP
GPIOA1	38	C3	I	

For more details, see the datasheet Ref. [2].

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16.10.2 API

Table 75: APIs for SD/eMMC Interface

Item		Description
HANDLE EMMC_CREATE(void)		
Parameter	None	
Return		If succeeded, return handle for such device If failed, return NULL.
Description		Function create handle. If memory allocation fails, return NULL
int EMMC_INIT(HANDLE handler)		
Parameter	handler	Device handle
Return		If succeeded, return ERR_NONE. If failed, return ERR_MMC_INIT.
Description		Initialize the SD/eMMC or SDIO card. If the function returns ERR_NONE, the card information is stored in the handle
int EMMC_READ(HANDLE handler, UINT32 dev_addr, VOID *p_data, UINT32 block_count)		
Parameter	handler	Device handle
	dev_addr	Address
	p_data	Data pointer
	block_count	Block counter for read
Return		If succeeded, return ERR_NONE.
Description		EMMC read command
int EMMC_WRITE(HANDLE handler, UINT32 dev_addr, VOID *p_data, UINT32 block_count)		
Parameter	handler	Device handle
	dev_addr	Address
	p_data	Data pointer
	block_count	Block counter for write
Return		If succeeded, return ERR_NONE.
Description		EMMC write command
void EMMC_SEND_CMD(HANDLE handler, UINT32 cmd, UINT32 cmd_arg)		
Parameter	handler	Device handle
	cmd	SDIO command without response. Defined in <SDIO.h>
	cmd_arg	SDIO command argument
Return		If succeeded, return TRUE. If failed, return FALSE.
Description		Send command to SDIO.
void EMMC_SEND_CMD_RES(HANDLE handler, UINT32 cmd, UINT32 cmd_arg, UINT32 *rsp)		
Parameter	handler	Device handle
	cmd	SDIO command with response
	cmd_arg	SDIO command argument
	rsp	Response pointer
Return		None
Description		After this function call, the response is stored in rsp.

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Item		Description
int EMMC_IOCTL(HANDLE handler, UINT32 cmd, VOID *data)		
Parameter	handler	Device handle
	cmd	The command that is defined in EMMC.h
	data	Data pointer
Return		If succeeded, return ERR_NONE.
Description		EMMC IOCTL command
int EMMC_CLOSE(HANDLE handler)		
Parameter	handler	Device handle
Return		If succeeded, return ERR_NONE.
Description		EMMC driver close command

16.10.3 How to Run

1. In the e²studio, import a project for the SD_EMMC sample application as follows:
   - *~/SDK/apps/common/examples/Peripheral/SD_EMMC/projects/da16200*
2. The sample application code is written in the following source file:
   ~/SDK/apps/common/examples/Peripheral/SD_EMMC/src/sd_emmc_sample.c
3. Build the DA16200 SDK, download the RTOS image to the DA16200 EVB, and reboot.
4. The sample will run as soon as boot is complete.

```
[/DA16200]  # emmc sample start
fail / total 0 / 100
[/DA16200] #
```

5. If the SD card is not ready, then the message "emmc_init fail" is returned.
6. Connect GPIOA[9:4] to the SD card socket as shown below.

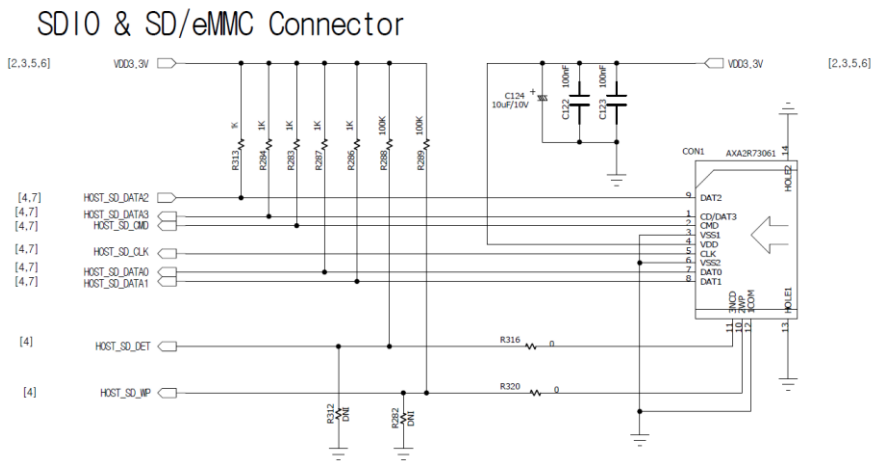

Figure 113: SDIO and SD/eMMC Connector

NOTE
The CMD and DATA pins of the SD card connections are open-drain at initialization. When the SD card initialization is not working normally, it needs to use smaller pull-up resisters for CMD and DATA pins or a shorter length jumper wire of the SD card connections.

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- GPIOA[9] - mSDeMMCIO_D0, GPIOA[8] - mSDeMMCIO_D1
- GPIOA[7] - mSDeMMCIO_D2, GPIOA[6] - mSDeMMCIO_D3
- GPIOA[5] - mSDeMMCIO_CLK, GPIOA[4] - mSDeMMCIO_CMD
- GPIOA[10] is not mandatory (for write protect function).

16.10.4 Sample Code

This sample code shows how the eMMC host writes random data to a slave memory card and reads back the written data to check if that data matches.

Function Emmc_verify() compares the written data with the data read from the SD memory card. The sector size of the SD memory card is 512 bytes. The “addr” variable value (210) in the code is just an example sector number in the SD memory card.

```
void emmc_init() {
...
    DA16X_CLOCK_SCGATE->Off_SysC_HIF = 0;
    DA16X_SYSCLOCK->CLK_DIV_EMMC = EMMC_CLK_DIV_VAL;
    DA16X_SYSCLOCK->CLK_EN_SDeMMC = 0x01;       // clock enable
...
```

- Set pin multiplexing.

```
/*
 * SDIO Master
 */
// GPIO[9] - mSDeMMCIO_D0,  GPIO[8] - mSDeMMCIO_D1
_da16x_io_pinmux(PIN_EMUX, EMUX_SDm);
// GPIO[5] - mSDeMMCIO_CLK,  GPIO[4] - mSDeMMCIO_CMD
_da16x_io_pinmux(PIN_CMUX, CMUX_SDm);
// GPIO[7] - mSDeMMCIO_D2,  GPIO[6] - mSDeMMCIO_D3
_da16x_io_pinmux(PIN_DMUX, DMUX_SDm);
```

- Create and initialize an SD/eMMC handle.

```
if (_emmc == NULL) {
    _emmc = EMMC_CREATE();
}
err = EMMC_INIT(_emmc);
```

16.11 User SFLASH Read/Write Example

16.11.1 How to Run

1. In the e²studio, import a project for the SD_EMMC sample application as follows:
   - *~/SDK/apps/common/examples/Peripheral/Sflash_API/projects/da16200*
2. The sample application code is written in the following source file:
   ~/SDK/apps/common/examples/Peripheral/Sflash_API/src/sflash_sample.c
3. Build the DA16200 SDK, download the RTOS image to the DA16200 EVB, and reboot.
4. After boot, the sample starts automatically.

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```
System Mode : Station Only (0)
>>> DA16x Supp Ver2.7 - 2020_07
>>> MAC address (sta0) : d4:3d:39:10:cc:78
>>> sta0 interface add OK
>>> Start STA mode...
SFLASH_API_SAMPLE
=== SFLASH Write Data =======================
>>>
- (len=128):
[00000000]  41 41 41 41 41 41 41 41 41 41 41 41 41 41 41 41  AAAAAAAAAAAAAAAA
[00000010]  41 41 41 41 41 41 41 41 41 41 41 41 41 41 41 41  AAAAAAAAAAAAAAAA
[00000020]  41 41 41 41 41 41 41 41 41 41 41 41 41 41 41 41  AAAAAAAAAAAAAAAA
[00000030]  41 41 41 41 41 41 41 41 41 41 41 41 41 41 41 41  AAAAAAAAAAAAAAAA
[00000040]  41 41 41 41 41 41 41 41 41 41 41 41 41 41 41 41  AAAAAAAAAAAAAAAA
[00000050]  41 41 41 41 41 41 41 41 41 41 41 41 41 41 41 41  AAAAAAAAAAAAAAAA
[00000060]  41 41 41 41 41 41 41 41 41 41 41 41 41 41 41 41  AAAAAAAAAAAAAAAA
[00000070]  41 41 41 41 41 41 41 41 41 41 41 41 41 41 41 41  AAAAAAAAAAAAAAAA
```

Figure 114: Sflash Example Sample Test

16.11.2 User Task

The user task of the sflash api sample application is defined as below and executed by the system. SAMPLE_SFLASH should be a unique name to create a task. This test is not related to network initialization and DPM mode.

~/SDK/apps/common/examples/Peripheral/Sflash_API/src/sample_apps.c

```
static const app_task_info_t sample_apps_table[] = {
  SAMPLE_SFLASH, user_sflash_test,1024, USER_PRI_APP(1), FALSE, FALSE,
      UNDEF_PORT,           RUN_ALL_MODE },
};
```

16.11.3 Sample Code

16.11.3.1 Application Initialization

The user_sflash_test function is run after the basic initialization is complete.

```
void SFLASH_API_sample(void *param)
{
    /* DO SOMETHING */
    PRINTF("SFLASH_API_SAMPLE\n");

    test_sflash_write();
    vTaskDelay(10);  // Dealy 100 msec

    test_sflash_read();
    vTaskDelete(NULL);

    return ;
}
```

16.11.3.2 Sflash Read and Write

```
// user sflash APIs

extern UINT user_sflash_read(UINT sflash_addr, VOID *rd_buf, UINT rd_size);
sflash_addr: see above user sflash area
rd_buf: buffer to which data is copied
rd_size: data size

extern UINT user_sflash_write(UINT sflash_addr, UCHAR *wr_buf, UINT wr_size);
sflash_addr: see above user sflash area
rd_buf: buffer from which data is copied to sflash_addr
rd_size: data size

...
```

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```
void test_sflash_write(void)
{
    UCHAR     *wr_buf = NULL;
    UINT      wr_addr;

#define       SFLASH_WR_TEST_ADDR SFLASH_USER_AREA_START
#define       TEST_WR_SIZE        SF_SECTOR_SZ

    wr_buf = (UCHAR *)malloc(TEST_WR_SIZE);

    if (wr_buf == NULL) {
        PRINTF("[%s] malloc fail ...\n", __func__);
        return;
    }

    memset(wr_buf, 0, TEST_WR_SIZE);

    for (int i = 0; i < TEST_WR_SIZE; i++) {
        wr_buf[i] = 0x41;   // A
    }

    wr_addr = SFLASH_WR_TEST_ADDR;

    PRINTF("=== SFLASH Write Data =====================\n");
    user_sflash_write(wr_addr, wr_buf, TEST_WR_SIZE);
}


void test_sflash_read(void)
{
    UCHAR     *rd_buf = NULL;
    UINT      rd_addr;
    UINT      status;

#define       SFLASH_RD_TEST_ADDR SFLASH_USER_AREA_START
#define       TEST_RD_SIZE        (1 * 1024)

    rd_buf = (UCHAR *)malloc(TEST_RD_SIZE);

    if (rd_buf == NULL) {
        PRINTF("[%s] malloc fail ...\n", __func__);
        return;
    }

    memset(rd_buf, 0, TEST_RD_SIZE);

    rd_addr = SFLASH_RD_TEST_ADDR;
    status = user_sflash_read(rd_addr, (VOID *)rd_buf, TEST_RD_SIZE);

    if (status == TRUE) {
        hex_dump(rd_buf, 128);
    }

    free(rd_buf);
}
```

NOTE
user_sflash_read/write is a blocking function.

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Take special care when runing this code under DPM mode enabled (sleep2 or sleep3 applications): when invoking user_sflash_write( ), make sure to get the result before the DPM sleeping API is invoked.

16.12 OTP

16.12.1 Introduction

The DA16200/DA16600 includes a one-time electrically field programmable non-volatile CMOS memory. This memory is to protect and manage major information essential for mass production and management of products, such as booting information, MAC address, serial number, and others.

The OTP is also used for storing secret information which is used for the advanced security functions such as secure booting, secure debugging, and secure asset storage. But this secret information cannot be accessed in a normal way of CPU read or write access so that it is protected from the external access.

Table 76: OTP Map

Offset	Field	Size (Bytes)
0x000	Renesas Reserved	1024
0x100	MAC Address #0 Low	4
0x101	MAC Address #0 High	4
0x102	MAC Address #1 Low	4
0x103	MAC Address #1 High	4
0x104	MAC Address #2 Low	4
0x105	MAC Address #2 High	4
0x106	MAC Address #3 Low	4
0x107	MAC Address #3 High	4
0x10A	XTAL Offset #0	4
0x10B	XTAL Offset #1	4
0x10C to 0x1FE	User Area	972

16.12.2 API

Table 77: OTP API List

Item		Description
void otp_mem_create(void)		
Parameter	None	
Return		None

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Item		Description

Description		Initialize OTP HW
		Before calling this function, it needs otp_clock_enable
		{
		DA16200_SYSCLOCK ->PLL_CLK_EN_4_PHY = 1;
		DA16200_SYSCLOCK ->CLK_EN_PHYBUS = 1;
		extern void DA16X_SecureBoot_OTPLock(unsigned int mode);
		DA16X_SecureBoot_OTPLock(1); // unlock
		#define CLK_GATING_OTP 0x50006048
		MEM_BYTE_WRITE(CLK_GATING_OTP, 0x00);
		otp_mem_create();
		}

void otp_mem_close(void)		
Parameter	None	
Return		None
Description		Close the OTP HW
int otp_mem_read(UINT32 offset, UINT32 *data)		
Parameter	offset	OTP memory offset (0x00 ~ 0x1FE)
	data	[out] data pointer of buffer
Return		OTP_OK if successes
Description		Each offset store 32-bit data Offset 0x00 to 0x2c used for secure purpose. So, it may not accessible. See Table 76
int otp_mem_write (UINT32 offset, UINT32 data)		
Parameter	offset	OTP memory offset (0x00 ~ 0x1FE)
	data	Data to write
Return		OTP_OK if successes
Description		Offset 0x00 to 0x2c used for secure purpose. Do not write any data within. See Table 76
int otp_mem_lock_read (UINT32 offset, UINT32 *data)		
Parameter	offset	Lock status offset. Always (0xFFF)
	data	Data pointer of lock status.
Return		OTP_OK if successes
Description		The OTP memory can be locked. Each lock bit can lock range ~ 0x40 For example: lock status value 0x00000002, it means that offset 0x40~0x7F OTP memory locked. lock bit 0 lock offset 0 ~ 0x3F lock bit 1 lock offset 0x40 ~ 0x7F lock bit 2 lock offset 0x80 ~ 0xBF lock bit 3 lock offset 0xC0 ~ 0xFF lock bit 4 lock offset 0x100 ~ 0x13F lock bit 5 lock offset 0x140 ~ 0x17F lock bit 6 lock offset 0x180 ~ 0x1BF lock bit 7 lock offset 0x1C0 ~ 0x1FE

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Item		Description
int otp_mem_lock_write (UINT32 offset, UINT32 *data)		
Parameter	offset	Lock status offset. Always (0xFFF)
	data	Lock status value.
Return		OTP_OK if successes
Description		Refer otp_mem_lock_read()

16.13 Bluetooth_LE_Coexistence

The Bluetooth® LE coexistence feature can be enabled and disabled through a configuration register. The activation scenarios based on the status of each pin are as follows:

- BT_sig0 (oWlanAct)
  - When asserted, the external BT/Bluetooth® LE device is expected to stop occupying RF.
  - This signal can be configured as always high by software to block the external BT/Bluetooth® LE device from occupying RF. See Section 16.13.4 for details
- BT_sig1 (iBtAct)
  - When asserted, DA16200/DA16600 stops occupying RF
- BT_sig2 (iBtPri)
  - This is optional.
  - When iBtPri is active, the DA16200/DA16600 will stop occupying RF when iBtAct is active even if a Wi-Fi transmission is in progress.

When both DA16200/DA16600 and BT/Bluetooth® LE try to transmit a packet at the same time, there is a configuration in the DA16200/DA16600 that determines which has the priority over the other.

When the priority of the DA16200/DA16600 is set to be higher than BT/Bluetooth® LE, it ignores iBtAct signal and transmits its packet anyway. When the priority of the DA16200/DA16600 is set to be lower than BT/Bluetooth® LE, it delays transmission of its packet until BT/Bluetooth® LE de-asserts the iBtAct signal.

Priority can be set through an API which is described in Section 16.13.4.

16.13.1 Pin Configuration

Table 78 shows the 3-pin configuration of Bluetooth® LE coexistence interface. Note that if the iBTPri pin is not controlled, it must be configured as pull-up or pull-down and not high-z to avoid any leakage.

Table 78: 3-Pin Bluetooth® LE Coexistence Pin Configuration

Signals	Description	I/O	DA16200 GPIO Num	Pin Number			
				DA16200	DA16200MOD	DA16600MOD	
						DA16200	DA14531
oWlanAct	Wi-Fi active signal	O	GPIOA8	30	25	35	48 (P0_5)
iBtAct	BT active signal	I	GPIOA9	29	24	34	3 (P0_6)
iBtPri	BT priority	I	GPIOA10	28	23	33	47 (P0_7)

When GPIOA8 and GPIOA9 are assigned as either an SDIO or SPI interface, only the GPIOA10 pin should be used for Bluetooth® LE Coexistence. In this case, the GPIOA10 pin must be connected to the iBtAct pin of the BT/Bluetooth® LE chipset to coordinate the use of the RF signal between the DA16200/DA16600 and BT/Bluetooth® LE chipsets Table 79 shows 1-pin configuration of Bluetooth® LE coexistence.

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Table 79: 1-Pin Bluetooth® LE Coexistence Pin Configuration

Signals	Description	I/O	DA16200 GPIO Num	Pin Number			
				DA16200	DA16200 MOD	DA16600MOD	
						DA16200	DA14531
iBtAct	BT active signal	I	GPIOA10	28	23	33	3 (P0_6)

16.13.2 Pin Multiplex

Pin multiplexing for the Bluetooth® LE coexistence feature can be configured by modifying the `initialize_bt_coex(void)` function in the "rf_meas_api.c" file as follows:

```
// pin mux setup for Bluetooth® LE coexistence
#ifndef __SUPPORT_BTCOEX_1PIN__
      _da16x_io_pinmux(PIN_EMUX, EMUX_BT);
#endif
     da16x_io_pinmux(PIN_FMUX, FMUX_GPIOBT);
```

16.13.3 SDK Feature Definition

The Bluetooth® LE coexistence feature can be enabled in the DA16200/DA16600 SDK in the "*config_generic_sdk.h*" file as following:

- 3-Pin Bluetooth® LE Coexistence

```
#define __SUPPORT_BTCOEX__            // BT Coexistences
```

- 1-Pin Bluetooth® LE Coexistence

```
#define __SUPPORT_BTCOEX__            // BT Coexistences
#define __SUPPORT_BTCOEX_1PIN__       // BT Coexistences with 1 pin
```

NOTE
When 1-pin Bluetooth® LE Coexistence is defined in "*config_generic_sdk.h*," the GPIOA10 pin should be connected to the iBtAct pin of the BT/Bluetooth® LE chipset.

16.13.4 API

Table 80: APIs for Bluetooth® LE Coexistence

Item	Description
void rf_meas_btcoex(uint8_t enable, uint8_t priority, uint8_t polarity);	
enable	0 or 1 (1: enable, 0: disable)
priority	Priority: 0, 1, 2, 3 0: BT > WLAN (BT priority is higher than WLAN) 1: BT = WLAN (BT and WLAN priorities are equal) 2: BT < WLAN (WLAN priority is higher than BT) 3: BT < WLAN, oWlanAct is forced to be always high.
polarity	Polarity: 0 and 1 for oWlanAct, iBtAct, and iBtPri PIN 0: Normal (Active-High) 1: Inverted (Active-low)
Return	None

Example code for the Bluetooth® LE coexistence API when using 3 pins:

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```
// The 1st Element means BT coexistence is enabled
rf_meas_btcoex(1, 0, 0); // 0: BLE win in conflict
rf_meas_btcoex(1, 2, 0); // 2: WLAN win in conflict
rf_meas_btcoex(1, 3, 0); // 3: Set oWlanAct pin high always, available in SDK
                            v3.2.6.0 or later
```

Example code for the Bluetooth® LE coexistence API when using 1 pin:

```
rf_meas_btcoex(1, 0, 0); // 1: BT coexistence is enabled, 0: BLE win in conflict
```

How to change the default setting:

After system startup, `rf_meas_btcoex(1, 0, 0)` is called in `user_main()` to set the default configuration of the Bluetooth® LE coexistence interface.

The `rf_meas_btcoex()` function can be called at anytime after system startup to reconfigure the priorities without requiring a reboot.

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Appendix A

A.1 Mosquitto 1.4.14 License

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Appendix B TX Power Table Edit

The DA16200/DA16600 SDK allows users to tune and edit TX Power (per channel) for FCC or country-dependent product customization/optimization. The country code and channels describe in Table 82.

Ch.2	11b				11g								11n							
Power Index	1Mbps	2Mbps	5.5Mbps	11Mbps	6Mbps	9Mbps	12Mbps	18Mbps	24Mbps	36Mbps	48Mbps	54Mbps	MCS0	MCS1	MCS2	MCS3	MCS4	MCS5	MCS6	MCS7
0	20.9	20.9	21.0	21.1	19.0	19.0	19.0	19.0	17.4	17.5	16.3	15.3	18.9	18.9	18.8	17.3	17.3	16.1	15.4	15.3
1	20.4	20.4	20.5	20.6	18.4	18.4	18.4	18.4	16.8	16.9	15.5	14.6	18.2	18.2	18.3	16.7	16.7	15.5	14.6	14.7
2	19.7	19.7	19.8	19.8	17.6	17.6	17.6	17.6	15.9	16.0	14.6	13.7	17.4	17.5	17.5	15.9	15.9	14.7	13.8	13.6
3	19.1	19.1	19.2	19.2	17.0	17.1	16.9	17.0	15.3	15.4	14.0	13.1	16.9	16.9	16.8	15.2	15.2	14.0	13.1	13.1
4	18.0	18.0	18.1	18.1	15.9	16.0	15.8	15.9	14.1	14.2	12.8	11.9	15.8	15.8	15.7	14.0	14.1	12.8	12.0	11.8
5	16.8	16.7	16.8	16.9	14.8	14.9	14.8	14.8	13.4	13.6	12.1	11.2	14.7	14.7	14.7	13.3	13.3	12.1	11.2	11.1
6	16.2	16.1	16.3	16.2	14.2	14.2	14.2	14.2	12.8	12.9	11.5	10.5	14.0	14.1	14.1	12.8	12.7	11.4	10.5	10.5
7	15.4	15.4	15.4	15.5	13.4	13.4	13.4	13.3	11.9	12.0	10.6	9.7	13.2	13.2	13.3	11.8	11.9	10.6	9.7	9.7
8	14.8	14.8	14.9	14.9	12.8	12.8	12.8	12.8	11.2	11.3	9.8	9.0	12.7	12.7	12.7	11.1	11.1	9.8	9.0	8.9
9	13.8	13.8	13.8	13.8	11.7	11.7	11.7	11.7	10.2	10.3	8.9	8.0	11.5	11.6	11.5	10.2	10.1	9.0	8.1	8.0
10	13.1	13.1	13.2	13.2	11.0	11.1	11.0	11.0	9.7	9.7	8.3	7.5	10.9	10.9	10.9	9.5	9.5	8.3	7.4	7.4
11	12.6	12.6	12.7	12.7	10.5	10.5	10.4	10.5	8.5	8.5	7.1	6.2	10.3	10.4	10.3	8.3	8.4	7.1	6.2	6.2

Figure 115: TX Power Table

NOTE
The 2.4 GHz band is divided into 14 channels at 5 MHz intervals centered at 2.412 GHz, starting with channel 1. The last channel (CH 14) has additional restrictions or cannot be used for all regulatory areas. ● TX power setting value range: 0x0 ~ 0xB ● Setting value for unsupported channel: 0xF

B.1 Tune TX Power

Users can tune and test TX power through CLI command and AT GUI tool. When the TX power value increases by 1 step, the actual TX power decreases by 0.8 dB. Unsupported channels should be set to 0xF. See the Chapter 6 and Appendix A of Ref. [6] on how to tune TX power using CLI or AT GUI tool.

This example shows the range of values for TX power.

Table 81: TX Power Setting Value Range

● TX power gap per value step: 0.8 dB ● TX power setting value range: 0x0 ~ 0xB ● Setting value for unsupported channel: 0xF

B.2 Apply Tuned TX Power to Main Image

The following procedure describes how to set the tuned TX power indices to the Main image.

1. In the DA16200/DA16600 SDK, open *~/FreeRTOS_SDK/core/system/src/common/main/sys_user_feature.c*.

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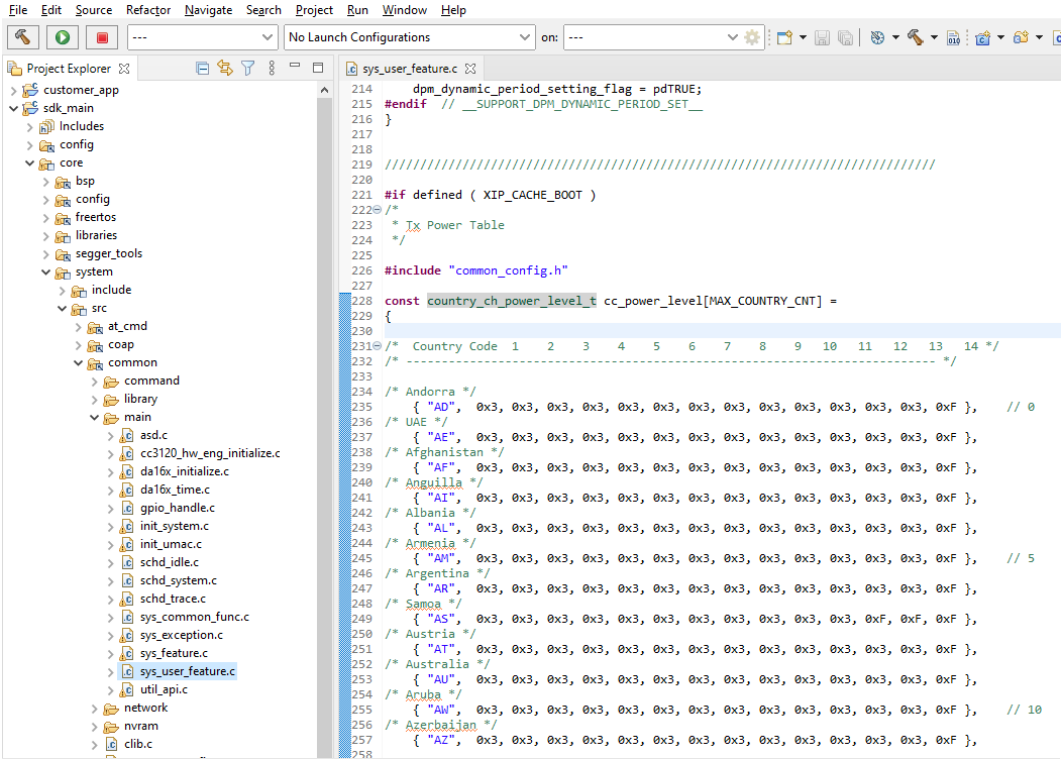

Figure 116: TX Power Table Source Code

The array cc_power_level contains the default values customized for FCC. Edit the power values for a specific country or the desired countries with tuned values. See Table 81 for more information.

2. Re-build the SDK.

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Appendix C Tips

C.1 Find/Optimize Stack Size for Applications

To check the stack size of the application, the DA16200/DA16600 has a tool (a console command) called **ps** that shows the list of threads and the status of each application stack.

Figure 117 is a snapshot of command ps when tcp_client_sample.c is run.

```
[/DA16200] # ps

 <<< Task information >>>
 Task count: 20  TotalTime: 507 Ticks
 ==============================================================================
 No TaskName     State    Run-Tm  Run-Per    Prio Stack-B Stack-E  S-Size Stack-L
 ==============================================================================
  1 system_laun Blocked       3      <1%       1 0xaf2b8 0xafeb0    3072    1476
  2 IDLE        Ready       496      97%       0 0xaff50 0xb00d8     400     316
  3 Tmr_Svc     Blocked       0      <1%      18 0xb0500 0xb0cf8    2048    1836
  4 Console_OUT Blocked       0      <1%       4 0xb4ce0 0xb50d8    1024     788
  5 Console_IN  Running       0      <1%       3 0xb58e0 0xb70d8    6144    5380
  6 wdt_kicking Blocked       0      <1%      31 0xb7590 0xb7788     512     420
  7 UmTaskletSv Blocked       0      <1%      20 0xb9130 0xb9528    1024     892
  8 UmTxNiTd    Blocked       0      <1%      19 0xb9a20 0xbb218    6144    5484
  9 UmRxMacTd   Blocked       1      <1%      20 0xbb2b8 0xbc2b0    4096    3188
 10 UmMacNiTd   Blocked       0      <1%      20 0xbc350 0xbd348    4096    3764
 11 @LmacMain   Blocked       1      <1%      22 0xbda58 0xbea50    4096    3776
 12 @UmacRx     Blocked       0      <1%      21 0xbeb58 0xbfd50    4608    4224
 13 UmWrkqSvc   Blocked       0      <1%      20 0xbff20 0xc0f18    4096    2964
 14 LwIP_init   Blocked       0      <1%      10 0xc1af0 0xc22e8    2048    1104
 15 lwIP        Blocked       1      <1%      21 0xc25f0 0xc2fe8    2560    1600
 16 wifi_ev_mon Blocked       0      <1%      17 0xc3088 0xc3680    1536     864
 17 da16x_supp  Blocked       5      <1%      18 0xc3988 0xc5980    8192    6028
 18 sntp_thread Blocked       0      <1%       7 0xc7a90 0xc8a88    4096    3284
 19 poll_gpio   Blocked       0      <1%       0 0xc8b28 0xc8f20    1024     932
 22 TCPC        Blocked       0      <1%       7 0xd41f0 0xd51e8    4096    2572
 ==============================================================================
```

Figure 117: Check Stack Size

TCPC is the name of the tread for this sample application, and the stack size is 1020 (which is defined in sample_apps.c).

This is a sample code of TCP Client.

```
…
#if defined (__TCP_CLIENT_SAMPLE__)
      { SAMPLE_TCP_CLI, tcp_client_sample, 1024, (tskIDLE_PRIORITY + 7), TRUE,
FALSE, TCP_CLI_TEST_PORT, RUN_ALL_MODE },
#endif // (__TCP_CLIENT_SAMPLE__)
…
```

Command `ps` shows the following information:

- Stack-B/E: the stack address
- S-Size: the stack size allocated
- Stack-L: peak usage size of the stack

To find and optimize the stack size for this application, for example if this application has four use cases, follow the steps below:

1. First, over-allocate stack memory as a precaution, like 2K, “just to be safe”.
2. Run each use case and examine the peak stack usage with command `ps`.
3. Allocate optimal memory based on peak usage information. If all the possible use case scenarios are confirmed, allocate the stack size with extra memory as a precaution.

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Appendix D Country Code and TX Power

This section lists the country codes that the DA16200/DA16600 supports and the supported channels of 2.4 GHz bandwidth in the STA and the Soft AP mode.

D.1 Country Code and Channels

Table 82: Country Code

Country Code	Country	STA Channels	Soft AP Channels
"AD"	Andorra	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“AE”	United Arab Emirates	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“AF”	Afghanistan	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“AI”	Anguilla	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“AL”	Albania	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“AM”	Netherlands Antilles	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“AR”	Argentina	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“AS”	American Samoa	1,2,3,4,5,6,7,8,9,10,11	1,2,3,4,5,6,7,8,9,10,11
“AT”	Austria	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“AU”	Australia	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“AW”	Aruba	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“AZ”	Azerbaijan	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“BA”	Bosnia and Herzegovina	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“BB”	Barbados	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“BD”	Bangladesh	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“BE”	Belgium	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“BF”	Burkina Faso	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“BG”	Bulgaria	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“BH”	Bahrain	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“BL”	Saint-Barthelemy	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“BM”	Bermuda	1,2,3,4,5,6,7,8,9,10,11	1,2,3,4,5,6,7,8,9,10,11
“BN”	Brunei Darussalam	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“BO”	Bolivia	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“BR”	Brazil	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“BS”	Bahamas	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“BT”	Bhutan	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“BY”	Belarus	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“BZ”	Belize	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“CA”	Canada	1,2,3,4,5,6,7,8,9,10,11	1,2,3,4,5,6,7,8,9,10,11
“CF”	Central African Republic	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“CH”	Switzerland	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“CI”	Ivory Coast	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13

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Country Code	Country	STA Channels	Soft AP Channels
“CL”	Chile	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“CN”	China	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“CO”	Colombia	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“CR”	Costa Rica	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“CU”	Cuba	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“CX”	Christmas Island	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
"CY”	Cyprus	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“CZ”	Czech Republic	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“DE”	Germany	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“DK”	Denmark	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“DM”	Dominica	1,2,3,4,5,6,7,8,9,10,11	1,2,3,4,5,6,7,8,9,10,11
“DO”	Dominican Republic	1,2,3,4,5,6,7,8,9,10,11	1,2,3,4,5,6,7,8,9,10,11
“DZ”	Algeria	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“EC”	Ecuador	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“EE”	Estonia	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“EG”	Egypt	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“ES”	Spain	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“ET”	Ethiopia	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“EU”	Europe	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“FI”	Finland	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“FM”	Micronesia, Federated States of	1,2,3,4,5,6,7,8,9,10,11	1,2,3,4,5,6,7,8,9,10,11
“FR”	France	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“GA”	Gabon	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“GB”	United Kingdom	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“GD”	Grenada	1,2,3,4,5,6,7,8,9,10,11	1,2,3,4,5,6,7,8,9,10,11
“GE”	Georgia	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“GF”	French Guiana	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“GH”	Ghana	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“GL”	Greenland	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“GP”	Guadeloupe	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“GR”	Greece	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“GT”	Guatemala	1,2,3,4,5,6,7,8,9,10,11	1,2,3,4,5,6,7,8,9,10,11
“GU”	Guam	1,2,3,4,5,6,7,8,9,10,11	1,2,3,4,5,6,7,8,9,10,11
“GY”	Guyana	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“HK”	Hong Kong	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“HN”	Honduras	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“HT”	Haiti	1,2,3,4,5,6,7,8,9,10,11	1,2,3,4,5,6,7,8,9,10,11
“HU”	Hungary	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13

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Country Code	Country	STA Channels	Soft AP Channels
“ID”	Indonesia	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“IE”	Ireland	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“IL”	Israel	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“IN”	India	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“IR”	Iran, Islamic Republic of	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“IS”	Iceland	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“IT”	Italy	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“JM”	Jamaica	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“JO”	Jordan	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
"JP”	Japan	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“KE”	Kenya	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“KH”	Cambodia	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“KN”	Saint Kitts and Nevis	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“KP”	North Korea	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“KR”	South Korea	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“KW”	Kuwait	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“KY”	Cayman Islands	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“KZ”	Kazakhstan	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“LB”	Lebanon	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“LC”	Saint Lucia	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“LI”	Liechtenstein	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“LK”	Sri Lanka	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“LS”	Sesotho	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“LT”	Lithuania	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“LU”	Luxembourg	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“LV”	Latvia	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“MA”	Morocco	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“MC”	Monaco	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“MD”	Moldova	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“ME”	Montenegro	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“MF”	Saint-Martin (French part)	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“MH”	Marshall Islands	1,2,3,4,5,6,7,8,9,10,11	1,2,3,4,5,6,7,8,9,10,11
“MK”	Macedonia, Republic of	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“MN”	Mongolia	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“MO”	Macao	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“MP”	Northern Mariana Islands	1,2,3,4,5,6,7,8,9,10,11	1,2,3,4,5,6,7,8,9,10,11
“MQ”	Martinique	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“MR”	Mauritania	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13

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Country Code	Country	STA Channels	Soft AP Channels
“MT”	Malta	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“MU”	Mauritius	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“MV”	Maldives	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“MW”	Malawi	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“MX”	Mexico	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“MY”	Malaysia	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“NG”	Nigeria	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“NI”	Nicaragua	1,2,3,4,5,6,7,8,9,10,11	1,2,3,4,5,6,7,8,9,10,11
“NL”	Netherlands	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“NO”	Norway	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“NP”	Nepal	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“NZ”	New Zealand	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
"OM”	Oman	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“PA”	Panama	1,2,3,4,5,6,7,8,9,10,11	1,2,3,4,5,6,7,8,9,10,11
“PE”	Peru	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“PF”	French Polynesia	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“PG”	Papua New Guinea	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“PH”	Philippines	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“PK”	Pakistan	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“PL”	Poland	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“PM”	Saint Pierre and Miquelon	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“PR”	Puerto Rico	1,2,3,4,5,6,7,8,9,10,11	1,2,3,4,5,6,7,8,9,10,11
“PT”	Portugal	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“PW”	Palau	1,2,3,4,5,6,7,8,9,10,11	1,2,3,4,5,6,7,8,9,10,11
“PY”	Paraguay	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“QA”	Qatar	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“RE”	Reunion	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“RO”	Romania	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“RS”	Serbia	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“RU”	Russian Federation	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“RW”	Rwanda	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“SA”	Saudi Arabia	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“SE”	Sweden	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“SG”	Singapore	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“SI”	Slovenia	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“SK”	Slovak Republic	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“SN”	Senegal	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“SR”	Suriname	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13

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Country Code	Country	STA Channels	Soft AP Channels
“SV”	El Salvador	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“SY”	Syrian Arab Republic	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“TC”	Turks and Caicos Islands	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“TD”	Chad	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“TG”	Togo	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“TH”	Thailand	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“TN”	Tunisia	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“TR”	Turkey	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“TT”	Trinidad and Tobago	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“TW”	Taiwan	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“TZ”	Tanzania	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“UA”	Ukraine	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
"UG”	Uganda	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“US”	United States of America	1,2,3,4,5,6,7,8,9,10,11	1,2,3,4,5,6,7,8,9,10,11
“UY”	Uruguay	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“UZ”	Uzbekistan	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“VC”	Saint Vincent and Grenadines	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“VE”	Venezuela	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“VI”	Virgin Islands	1,2,3,4,5,6,7,8,9,10,11	1,2,3,4,5,6,7,8,9,10,11
“VN”	Vietnam	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“VU”	Vanuatu	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“WF”	Walls and Futuna Islands	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“WS”	Samoa	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“YE”	Yemen	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“YT”	Mayotte	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“ZA”	South Africa	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“ZW”	Zimbabwe	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“00”	Worldwide	1,2,3,4,5,6,7,8,9,10,11,12,13	1,2,3,4,5,6,7,8,9,10,11,12,13
“XX”		1,2,3,4,5,6,7,8,9,10,11	1,2,3,4,5,6,7,8,9,10,11

D.2 Programming

All of the power level settings are 0x0 as default setting, so it should be set as required for the customer’s specifications and requirement. The power table consists of two types, one is for OFDM and the other is for DSSS. DA16200/DA16600 will refer to the levels either of the cc_power_level table for OFDM mode or the cc_power_level_dsss for DSSS mode.

In the DA16200/DA16600 SDK, users can change the supporting “country code list” for their product. See Table 81 and Table 83.

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NOTE
The 2.4 GHz band is divided into 14 channels at 5 MHz intervals centered at 2.412 GHz, starting with channel 1. The last channel (CH 14) has additional restrictions or cannot be used for in all regulatory areas. - TX power setting value range: 0x0 ~ 0xB Setting value for unsupported channel: 0xF

- *FreeRTOS_SDK/apps/da6200(da16600)/get_started/src/apps/main/user_system_feature.c*

This is programming examples of country codes.

Table 83: Programming Example for Country Code

```
const country_ch_power_level_t cc_power_level[MAX_COUNTRY_CNT] =
{

/*  Country  1    2    3    4    5    6    7    8    9   10   11   12   13  14 */
/* ------------------------------------------------------------------------------ */

/* Andorra */
  { "AD",  0x0, 0x0, 0x0, 0x0, 0x0, 0x0, 0x0, 0x0, 0x0, 0x0, 0x0, 0x0, 0x0, 0xF },
/* UAE */
  { "AE",  0x0, 0x0, 0x0, 0x0, 0x0, 0x0, 0x0, 0x0, 0x0, 0x0, 0x0, 0x0, 0x0, 0xF },
/* Afghanistan */
  { "AF",  0x0, 0x0, 0x0, 0x0, 0x0, 0x0, 0x0, 0x0, 0x0, 0x0, 0x0, 0x0, 0x0, 0xF },
```

```
const country_ch_power_level_t cc_power_level_dsss[MAX_COUNTRY_CNT] =
{

/*  Country  1    2    3    4    5    6    7    8    9   10   11   12   13  14 */
/* ------------------------------------------------------------------------------ */

/* Andorra */
  { "AD",  0x0, 0x0, 0x0, 0x0, 0x0, 0x0, 0x0, 0x0, 0x0, 0x0, 0x0, 0x0, 0x0, 0xF },
/* UAE */
  { "AE",  0x0, 0x0, 0x0, 0x0, 0x0, 0x0, 0x0, 0x0, 0x0, 0x0, 0x0, 0x0, 0x0, 0xF },
/* Afghanistan */
  { "AF",  0x0, 0x0, 0x0, 0x0, 0x0, 0x0, 0x0, 0x0, 0x0, 0x0, 0x0, 0x0, 0x0, 0xF },
```

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Appendix E How to Use J-Link Debugger

See Section 5.9 of Ref. [4].

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Appendix F Create RTOS Image for fcCSP Using SDK v3.2.7.1 or Earlier

For fcCSP type package, to create a RTOS image with the DA16200/DA16600 SDK, change the files as shown below, and then follow the Build SDK instructions described in Section 3.7.

- Library file for Low-Power:
  - ~/FreeRTOS_SDK/library/liblmac.a.fcCSP_LP (or liblmac.fcCSP.LP.a) → ~/FreeRTOS_SDK/library/liblmac.a
- Library file for Normal-Power:
  - ~/FreeRTOS_SDK/library/liblmac.a.fcCSP_NP (or liblmac.fcCSP.NP.a) → ~/FreeRTOS_SDK/library/liblmac.a
- Compile feature:
  - ~/FreeRTOS_SDK/apps/da16200/get_started/include/user_main/sys_common_features.h
    - `#undef __FOR_FCCSP_SDK__` → `#define __FOR_FCCSP_SDK__`
    - In case of Low-Power: `#define __FCCSP_LOW_POWER__`
    - In case of Normal-Power: `#undef __FCCSP_LOW_POWER__`

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Revision History

Revision	Date	Description
2.2	Aug. 18, 2023	● Updated MCU transmission protocol changes in 13.6.2 ● Added Certificate API in Section 5 ● Added parameters into Section 8.1.1 ○ DA16X_CONF_INT_HIDDEN_0 ○ DA16X_CONF_INT_AUTH_MODE_0 ○ DA16X_CONF_INT_EAP_PHASE1_0 ○ DA16X_CONF_INT_EAP_PHASE2_0 ● Added parameters into Section 8.1.2 ○ DA16X_CONF_STR_EAP_IDENTITY ○ DA16X_CONF_STR_EAP_PASSWORD ● Added WPA Engterprise Sample code into Section 8.1.3 ● Added Watchdog service in Section 7 ● Changed IDE to e²studio ● Changed description about fcCSP Low Power RTOS Image in Section 3.7.1
2.1	May 31, 2023	Added missing section of the Introduction 3
2.0	May 19, 2023	● Merged MQTT Programmer Guide, FreeROTS OTA Update, and FreeRTOS Example Application Manual ● Added the details for Bluetooth® LE Coexistence part in Section 16.13 ● Modified wakeup status in Table 59
1.9	Jan. 04, 2023	● Added Bluetooth® LE Coexistence part in Section 16.13 ● Memory map updated: adjustable Bluetooth® LE FW size and user area in DA16600 ● Updated Figures of Eclipse IDE screen capture
1.8	Oct. 24, 2022	Added TX power setting value range and step in Appendix B.1
1.7	Aug. 11, 2022	Changed TLS certificate area index number of SFLASH area : #0, #1, #2, #3 → #1, #2, #3, #4 in section 13.2
1.6	Jun. 14, 2022	● Updated company name of Reference documents ● Updated SFLASH memory map for the DA16200/DA16600in section 13.2 ● Updated TX power table programming in Appendix B.2
1.5	Mar. 28, 2022	Updated logo, disclaimer, and copyright.
1.4	Dec. 22, 2021	Added description about fcCSP Low Power RTOS Image.
1.3	Nov. 26, 2021	Title was changed.
1.2	Nov. 09, 2021	TW Editorial.
1.1	Oct. 25, 2021	Added description about OTP.
1.0	Apr. 13, 2021	First Release.

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Status	Definition
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