ANR003 PROTEUS-I

LOW POWER APPLICATION WITH PERIODIC WAKE-UP

VERSION 2.3

OCTOBER 21, 2019
# Revision history

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<th>HW version</th>
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<td>• Initial version</td>
<td>February 2017</td>
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<tr>
<td>2.0</td>
<td>2.1</td>
<td>• New corporate design</td>
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<tr>
<td>2.1</td>
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<td>• Updated product name from AMB2621 to Proteus-I</td>
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<td>2.2</td>
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<td>• Updated file name to new AppNote name structure. Updated important notes, legal notice &amp; license terms chapters.</td>
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1 Introduction

The Proteus-I is a Bluetooth® module based on Nordic Semiconductors nRF52832 SoC that brings various BLE and low power features. The SoC has a system-off mode (deep-sleep) that allows to preserve power when the module is sleeping. Leaving this mode can be triggered by pin interrupt, low power comparator or NFC (NFC pins can be accessed on the Proteus-I-EV).

However, in many applications a periodic wake-up from a sleep mode is needed. Therefore the chip offers a system-on mode that wakes on any selected event.

In this application note the realization and test results of a periodic wake-up using the real time clock (RTC) is presented. The tested implementation sets the module to sleep and wakes it periodically. While awake, the module advertises and waits for incoming connections. Therefore the Nordic "UART Example for peripheral devices" is taken and updated in a few steps such that the periodic wake-up and the low power capabilities of the chip can be demonstrated using messages on the UART.

The test results in chapter 3 show that we can periodically switch between sleep and normal mode. When sleeping it consumes less than 2µA with RTC enabled.
2 Realization

2.1 Prerequisites

- The evaluation board Proteus-I-EV and a Segger flash adapter

- Software provided by Nordic Semiconductor: The BLE stack Softdevice S132 V3.0.0, the software development kit SDK nRF5 V 12.1.0 and the example code "Nordic UART Example for peripheral devices" (ble_app_uart_pca10040_s132)

- Keil µVision installed on your PC (the example base upon version 5.20.0.0)

2.2 Implementation

The goal is to update the Nordic "UART example" such that the module goes to sleep (system on) mode if no connection request was received during advertising for a predefined time. After a sleep period, the module is supposed to wake up after a predefined time and start advertising again to be ready for incoming connections. To realize the automatic wake-up a timer will be implemented that uses the real time clock (RTC) and the internal low frequency oscillator (so no external 32768 Hz watch crystal is needed).

Due to copyright rules of the Nordic SDK we are not allowed to supply you with a zip file containing all needed files for this demonstration. Please install the SDK from Nordic and add or patch the corresponding files and project settings.

To do so, please perform the following steps:
1. Load the Nordic "UART example for peripherals" from the Nordic SDK nRF5 V 12.1.0 and check whether it compiles without errors.

2. Update the board file, such that the code can run on the Proteus-I-EV platform:
   a) You find these changes in the Appendix (Boards.h and AMB2621.h). You need to create and add AMB2621.h and patch the project settings and some files of the SDK’s demo project. Following up the needed changes (already contained in the files of the appendix)
   b) Update the pin numbers according to the Proteus-I design.
   c) Set the RTS and CTS UART pins to 0, since they are not used in this example.
   d) Invert the LEDs. Each LED takes about 3mA, when lighted. Thus we prefer to flash them only for a short time.
   e) Use the internal RC-oscillator as low frequency clock.

3. Compile the updated code and check for errors.

4. Flash the BLE stack S132 V3.0.0 and the compiled code onto the module. Check if the Nordic UART example still does its job. If so, you have the original Nordic UART Example ported to the Proteus-I.

   In case, you haven’t loaded the Nordic Softdevice onto the chip, erase the full chip and load the Nordic Softdevice on it.

5. Then start with the modifications to realize the above specifications. First enable the DCDC to save current.

   err_code = sd_power_dcdc_mode_set(NRF_POWER_DCDC_ENABLE);
   APP_ERROR_CHECK(err_code);

6. This needs to be done in the ble_stack_init() function.

7. Set the APP_ADV_TIMEOUT_IN_SECONDS to 5s for example. This is the timeout after which the module goes to sleep mode, when no connection request was received during advertising.

8. Then implement a timer:

   APP_TIMER_DEF(wakeup_timer_id);
   err_code = app_timer_create(&wakeup_timer_id, APP_TIMER_MODE_SINGLE_SHOT, wakeup_timer_handler);
   APP_ERROR_CHECK(err_code);
void wakeup_timer_handler(void * p_context)
{
    app_timer_stop(wakeup_timer_id);
}

9. In function on_adv_evt() change the content of the BLE_ADV_EVT_IDLE case. When advertising timeouts, let the LED indicate idle, close the UART and start the timer. Here we also choose 5s as sleep time. This will be the time after which the module will wake-up again.

    case BLE_ADV_EVT_IDLE:
        err_code = bsp_indication_set(BSP_INDICATE_IDLE);
        APP_ERROR_CHECK(err_code);
        app_timer_start(wakeup_timer_id,
                        APP_TIMER_TICKS(5000, APP_TIMER_PRESCALER), NULL);
        app_uart_close();
        break;

In this case, all peripherals are stopped and the power_manage() function in the main loop puts the system to system on mode.

10. Then fill the wakeup_timer_handler() function. It has to re-enable the UART, re-initialize the LEDs and restart advertising upon wake-up.

    void wakeup_timer_handler(void * p_context)
    {
        app_timer_stop(wakeup_timer_id);
        uart_init();
        uint32_t err_code = bsp_init(BSP_INIT_LED | BSP_INIT_BUTTONS,
                                    APP_TIMER_TICKS(100, APP_TIMER_PRESCALER),
                                    bsp_event_handler);
        APP_ERROR_CHECK(err_code);
        err_code = ble_advertising_start(BLE_ADV_MODE_FAST);
        APP_ERROR_CHECK(err_code);
    }

11. Re-compile and flash the new code onto the module.

12. Disconnect the flasher and resource the module, such that the chip runs in normal mode.

   If you do not disconnect the flasher it is possible that the nrf52 stays in debug mode.

   Also check the Jumper JP4 on the EV board that it is set.

13. Now, you can see that the module advertises for 5s and sleeps for 5s. During advertising, the LED_3 of the Proteus-I-EV flashes periodically. When the module sleeps, this LED is off constantly.
3 Test results

When running the new code, the Proteus-I starts advertising after power-up. In this case the LED_3 of the Proteus-I-EV is flashing periodically and the chip needs about 1.42mA. When no connection request was received until the advertising timeout (here 5s) was received, the module stops advertising and disables the UART. Since no events occur after switching of these peripherals, the core can go to sleep (system on mode). Until the core is woken up by the timer, the module consumes less than 2μA. When the timer re-enables the UART and starts the advertising again, the module is in normal mode with a current consumption as before (1.42mA). This will be repeated periodically.

<table>
<thead>
<tr>
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<th>Operation mode with UART on and advertising</th>
<th>Sleep (System on) mode</th>
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<td>Power consumption</td>
<td>1.42mA</td>
<td>&lt; 2µA</td>
</tr>
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<td>Next step</td>
<td>Go to sleep mode, when no connection request was received for 5s</td>
<td>Wake-up from sleep after 5s using the RTC</td>
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3.1 Power consumption notes

Please note that the power consumption during advertising time can be decreased either. First of all, it depends on the advertising timing settings (how often an advertise packet is sent). Furthermore, switching off the UART yields in a significant saving of power. This can be a solution to realize a lowest power application with periodic wake-up.
4 Appendix

Boards.h Add the additional case for the Proteus-I (AMB2621) board:

```c
#elif defined(BOARD_AMB2621)
#include "AMB2621.h"
```

And change the project settings, on tab c/c++, Section "Preprocessor Symbols -> Define" of the demo project to use "BOARD_AMB2621" instead of "BOARD_PCA10040".

AMB2621.h

```c
#ifndef AMB2621_H
#define AMB2621_H

/* PINS of the nRF52:
 * The pins are named w.r.t their function in the AMB2621 standard firmware
 */

#define NRF_PIN_LED_1 0
#define NRF_PIN_LED_2 1
#define NRF_PIN_UARTTX 2
#define NRF_PIN_UARTRX 3
#define NRF_PIN_UARTRTS 4
#define NRF_PIN_BOOT 5
#define NRF_PIN_6 6
#define NRF_PIN_7 7
#define NRF_PIN_8 8
#define NRF_PIN_CUSTOM_9 /* corresponds to AMB2621_PIN_9 */
#define NRF_PIN_OPERATIONMODE 10 /* corresponds to AMB2621_PIN_8 */
#define NRF_PIN_11 11
#define NRF_PIN_12 12
#define NRF_PIN_13 13
#define NRF_PIN_14 14
#define NRF_PIN_15 15
#define NRF_PIN_16 16
#define NRF_PIN_17 17
#define NRF_PIN_18 18
#define NRF_PIN_19 19
#define NRF_PIN_20 20
#define NRF_PIN_RESET 21
#define NRF_PIN_22 22
#define NRF_PIN_23 23
#define NRF_PIN_24 24
#define NRF_PIN_25 25
#define NRF_PIN_26 26
#define NRF_PIN_27 27
#define NRF_PIN_UARTCTS 28
#define NRF_PIN_SLEEP 29
#define NRF_PIN_30 30
#define NRF_PIN_31 31

// LEDs definitions for AMB2621
#define LEDS_NUMBER 2
#define LEDS_LIST {NRF_PIN_LED_1, NRF_PIN_LED_2}
#define BSP_LED_0 NRF_PIN_LED_1
#define BSP_LED_1 NRF_PIN_LED_2

#endif
```

/* all LEDs are lit when GPIO is low */
#define LEDS_ACTIVE_STATE 1
#define LEDS_INV_MASK LEDS_MASK

// Buttons definitions for AMB2621
#define BUTTONS_NUMBER 1
#define BUTTONS_LIST [NRF_PIN_SLEEP]
#define BSP_BUTTON_0 NRF_PIN_SLEEP
#define BUTTON_PULL NRF_GPIO_PIN_PULLUP
#define BUTTONS_ACTIVE_STATE 0

// UART definitions for AMB2621
#define RX_PIN_NUMBER NRF_PIN_UARTRX
#define TX_PIN_NUMBER NRF_PIN_UARTTX
#define RTS_PIN_NUMBER NRF_PIN_UARTRTS
#define CTS_PIN_NUMBER NRF_PIN_UARTCTS

// Low frequency clock source to be used by the SoftDevice
#define NRF_CLOCK_LFCLKSRC {
    .source = NRF_CLOCK_LF_SRC_RC,
    .rc_ctiv = 16,
    .rc_temp_ctiv = 2,
}
#endif // AMB2621_H

main.c

/* Copyright (c) 2014 Nordic Semiconductor. All Rights Reserved.
 * The information contained herein is property of Nordic Semiconductor ASA.
 * Terms and conditions of usage are described in detail in NORDIC
 * SEMICONDUCTOR STANDARD SOFTWARE LICENSE AGREEMENT.
 * Licensees are granted free, non-transferable use of the information. NO
 * WARRANTY of ANY KIND is provided. This heading must NOT be removed from
 * the file.
 */

#define AMBER_AN_VERSION 1.0

/* * @file
 * @defgroup ble_sdk_uart_over_ble_main main.c
 * @{-
 * @ingroup ble_sdk_app_nus_eval
 * @brief UART over BLE application main file.
 * This file contains the source code for a sample application that uses the Nordic UART service.
 * This application uses the @ref srvlib_conn_params module.
 * @{-
 * @include <stdint.h>
 * @include <string.h>
 * @include "nordic_common.h"
 * @include "nrf.h"
 * @include "ble.h"
 * @include "ble_advdata.h"
 * @include "ble_advertising.h"
 * @include "ble_conn_params.h"
 * @include "softdevice_handler.h"
 * @include "app_timer.h"
 * @include "app_button.h"
 * @include "ble_nus.h"
 * @include "app_uart.h"
 * @include "app_util_platform.h"
 * @include "bsp.h"
 * @include "bsp_btn_ble.h"
 #define IS_SRVC_CHANGED_CHARACT_PRESENT 0 /**< Include the service_changed characteristic. If not enabled, the server's
database cannot be changed for the lifetime of the device. */
#endif // AMB2621_H


```c
#define CENTRAL_LINK_COUNT 0
/*! Number of central links used by the application. When changing this number remember to adjust the RAM settings */
#define PERIPHERAL_LINK_COUNT 1
/*! Number of peripheral links used by the application. When changing this number remember to adjust the RAM settings */
#define DEVICE_NAME "Nordic_UART"
/*! Name of device. Will be included in the advertising data. */
#define NUS_SERVICE_UUID_TYPE BLE_UUID_TYPE_VENDOR_BEGIN
/*! UUID type for the Nordic UART Service (vendor specific). */
#define APP_ADV_INTERVAL 64
/*! The advertising interval (in units of 0.625 ms. This value corresponds to 40 ms). */
#define APP_ADV_TIMEOUT_IN_SECONDS 5
/*! The advertising timeout (in units of seconds). */
#define APP_TIMER_PRESCALER 0
/*! Value of the RTC1 PRESCALER register. */
#define APP_TIMER_OP_QUEUE_SIZE 4
/*! Size of timer operation queues. */
#define MIN_CONN_INTERVAL MSEC_TO_UNITS(20, UNIT_1_25_MS)
/*! Minimum acceptable connection interval (20 ms), Connection interval uses 1.25 ms units. */
#define MAX_CONN_INTERVAL MSEC_TO_UNITS(75, UNIT_1_25_MS)
/*! Maximum acceptable connection interval (75 ms), Connection interval uses 1.25 ms units. */
#define SLAVE_LATENCY 0
/*! Slave latency. */
#define CONN_SUP_TIMEOUT MSEC_TO_UNITS(4000, UNIT_10_MS)
/*! Connection supervisory timeout (4 seconds), Supervision Timeout uses 10 ms units. */
#define FIRST_CONN_PARAMS_UPDATE_DELAY APP_TIMER_TICKS(5000, APP_TIMER_PRESCALER)
/*! Time from initiating event (connect or start of notification) to first time sd_ble_gap_conn_param_update is called (5 seconds). */
#define NEXT_CONN_PARAMS_UPDATE_DELAY APP_TIMER_TICKS(30000, APP_TIMER_PRESCALER)
/*! Time between each call to sd_ble_gap_conn_param_update after the first call (30 seconds). */
#define MAX_CONN_PARAMS_UPDATE_COUNT 3
/*! Number of attempts before giving up the connection parameter negotiation. */
#define DEAD_BEEF 0xDEADBEEF
/*! Value used as error code on stack dump, can be used to identify stack location on stack unwind. */
#define UART_TX_BUF_SIZE 256
/*! UART TX buffer size. */
#define UART_RX_BUF_SIZE 256
/*! UART RX buffer size. */
static ble_nus_t m_nus;
/*! Structure to identify the Nordic UART Service. */
static uint16_t m_conn_handle = BLE_CONN_HANDLE_INVALID;
/*! Handle of the current connection. */
static ble_uuid_t m_adv_uuids[] = {{BLE_UUID_NUS_SERVICE, NUS_SERVICE_UUID_TYPE}};
/*! Universally unique service identifier. */
```
for (uint32_t i = 0; i < length; i++)
{
    while (app_uart_put(p_data[i]) != NRF_SUCCESS);
}
while (app_uart_put(‘\r’)) != NRF_SUCCESS);
while (app_uart_put(‘\n’) != NRF_SUCCESS);

// @snippet [Handling the data received over BLE]

static void services_init (void)
{
    uint32_t err_code;
    ble_nus_init_t nus_init;
    memset(&nus_init, 0, sizeof(nus_init));
    nus_init.data_handler = nus_data_handler;
    err_code = ble_nus_init(&m_nus, &nus_init);
    APP_ERROR_CHECK(err_code);
}

static void on_conn_params_evt(ble_conn_params_evt_t * p_evt)
{
    uint32_t err_code;
    if (p_evt->evt_type == BLE_CONN_PARAMS_EVT_FAILED)
    {
        err_code = sd_ble_gap_disconnect(m_conn_handle, BLE_HCI_CONN_INTERVAL_UNACCEPTABLE);
        APP_ERROR_CHECK(err_code);
    }
}

static void conn_params_init(void)
{
    uint32_t err_code;
    ble_conn_params_init_t cp_init;
    memset(&cp_init, 0, sizeof(cp_init));
    cp_init.p_conn_params = NULL;
    cp_init.first_conn_params_update_delay = FIRST_CONN_PARAMS_UPDATE_DELAY;
    cp_init.next_conn_params_update_delay = NEXT_CONN_PARAMS_UPDATE_DELAY;
    cp_init.max_conn_params_update_count = MAX_CONN_PARAMS_UPDATE_COUNT;
    cp_init.start_on_notify_cccd_handle = BLE_GATT_HANDLE_INVALID;
    cp_init.disconnect_on_fail = false;
    cp_init.conn_params_evt = on_conn_params_evt;
    cp_init.error_handler = conn_params_error_handler;
    err_code = ble_conn_params_init(&cp_init);
    APP_ERROR_CHECK(err_code);
}

static void sleep_mode_enter(void)
{
    uint32_t err_code = bsp_indication_set(BSP_INDICATE_IDLE);
    APP_ERROR_CHECK(err_code);
    err_code = bsp_btn_ble_sleep_mode_prepare();
    APP_ERROR_CHECK(err_code);
    err_code = sd_power_system_off();
    APP_ERROR_CHECK(err_code);
}

// @brief Function for initializing services that will be used by the application.

// @brief Function for handling an event from the Connection Parameters Module.

// @brief Function for handling errors from the Connection Parameters module.

// @brief Function for initializing the Connection Parameters module.

// @brief Function for putting the chip into sleep mode.

// @note This function will not return.
/* @brief Function for handling advertising events. */

/* @details This function will be called for advertising events which are passed to the application. */

/* @param[in] ble_adv_evt Advertising event. */

static void on_adv_evt(ble_adv_evt_t ble_adv_evt) {
    uint32_t err_code;
    switch (ble_adv_evt) {
    case BLE_ADV_EVT_FAST:
        err_code = bsp_indication_set(BSP_INDICATE_ADVERTISING);
        APP_ERROR_CHECK(err_code);
        break;
    case BLE_ADV_EVT_IDLE:
        /* switch UART off and indicate IDLE, we now go to system on mode */
        err_code = bsp_indication_set(BSP_INDICATE_IDLE);
        APP_ERROR_CHECK(err_code);
        app_timer_start(wakeup_timer_id, APP_TIMER_TICKS(5000, APP_TIMER_PRESCALER), NULL);
        app_uart_close();
        break;
    default:
    break;
    }
}

/* @brief Function for the application’s SoftDevice event handler. */

/* @param[in] p_ble_evt SoftDevice event. */

static void on_ble_evt(ble_evt_t * p_ble_evt) {
    uint32_t err_code;
    switch (p_ble_evt->header.evt_id) {
    case BLE_GAP_EVT_CONNECTED:
        err_code = bsp_indication_set(BSP_INDICATE_CONNECTED);
        APP_ERROR_CHECK(err_code);
        m_conn_handle = p_ble_evt->evt.gap_evt.conn_handle;
        break; // BLE_GAP_EVT_CONNECTED
    case BLE_GAP_EVT_DISCONNECTED:
        err_code = bsp_indication_set(BSP_INDICATE_IDLE);
        APP_ERROR_CHECK(err_code);
        m_conn_handle = BLE_CONN_HANDLE_INVALID;
        break; // BLE_GAP_EVT_DISCONNECTED
    case BLE_GAP_EVT_SEC_PARAMS_REQUEST:
        // Pairing not supported
        err_code = sd_ble_gap_sec_params_reply(m_conn_handle, BLE_GAP_SEC_STATUSPAIRINGNOTSUPP, NULL, NULL);
        APP_ERROR_CHECK(err_code);
        break; // BLE_GAP_EVT_SEC_PARAMS_REQUEST
    case BLE_GATTS_EVT_SYS_ATTR_MISSING:
        // No system attributes have been stored.
        err_code = sd_ble_gatts_sys_attr_set(m_conn_handle, NULL, 0, 0);
        APP_ERROR_CHECK(err_code);
        break; // BLE_GATTS_EVT_SYS_ATTR_MISSING
    case BLE_GATTC_EVT_TIMEOUT:
        // Disconnect on GATT Client timeout event.
        err_code = sd_ble_gap_disconnect(p_ble_evt->evt.gattc_evt.conn_handle,
                                          BLE_HCI_REMOTE_USER_TERMINATED_CONNECTION);
        APP_ERROR_CHECK(err_code);
        break; // BLE_GATTC_EVT_TIMEOUT
    case BLE_GATTS_EVT_TIMEOUT:
        // Disconnect on GATT Server timeout event.
        err_code = sd_ble_gap_disconnect(p_ble_evt->evt.gattc_evt.conn_handle,
                                          BLE_HCI_REMOTE_USER_TERMINATED_CONNECTION);
        APP_ERROR_CHECK(err_code);
        break; // BLE_GATTS_EVT_TIMEOUT
    case BLE_EVT_USER_MEM_REQUEST:
        err_code = sd_ble_gatts_user_mem_reply(p_ble_evt->evt.gattc_evt.conn_handle, NULL);
        APP_ERROR_CHECK(err_code);
        break; // BLE_EVT_USER_MEM_REQUEST
    case BLE_GATTS_EVT_RW_AUTHORIZE_REQUEST:
        { /* ble_gatts_rwlock_authorize_request_t req; */
          ble_gatts_rwlock_authorize_reply_params_t auth_reply; /* req = p_ble_evt->evt.gatts_evt.params.authorize_request; */
          if (req.type != BLE_GATTS_AUTHORIZE_TYPE_INVALID) {
            if ((req.request.write.op == BLE_GATTS_OP_PREP_WRITE_REQ) 
                || (req.request.write.op == BLE_GATTS_OP_EXEC_WRITE_REQ NOW) 
                || (req.request.write.op == BLE_GATTS_OP_EXEC_WRITE_REQ CANCEL)) {
                auth_reply.type = BLE_GATTS_AUTHORIZE_TYPE_WRITE;
                auth_reply.request = BLE_GATTS_AUTHORIZE_TYPE_WRITE;
            } else {
                /* else */
            }
        }
    case BLE_GATTS.EVT_RW_AUTHORIZE_REQUEST:
    { /* ble_gatts_rwlock_authorize_request_t req; */
      ble_gatts_rwlock_authorize_reply_params_t auth_reply; /* req = p_ble_evt->evt.gatts_evt params.authorize_request; */
      if (req.type != BLE_GATTS_AUTHORIZE_TYPE_INVALID) {
        if ((req.request.write.op == BLE_GATTS_OP_PREP_WRITE_REQ) 
            || (req.request.write.op == BLE_GATTS_OP_EXEC_WRITE_REQ_NOW) 
            || (req.request.write.op == BLE_GATTS_OP_EXEC_WRITE_REQ CANCEL)) {
            auth_reply.type = BLE_GATTS_AUTHORIZE_TYPE_WRITE;
            auth_reply.request = BLE_GATTS_AUTHORIZE_TYPE_WRITE;
        } else {
            /* else */
        }
    }
}
```c
else {
    auth_reply.type = BLE_GATTS_AUTHORIZE_TYPE_READ;
    auth_reply.params.write.gatt_status = APP_FEATURE_NOT_SUPPORTED;
    err_code = sd_ble_gatts_rw_authorize_reply(p_ble_evt->evt.gatts_evt.conn_handle, &auth_reply);
    APP_ERROR_CHECK(err_code);
}
} break; // BLE_GATTS_EVT_RW_AUTHORIZE_REQUEST
#endif

#define BLE_GATTS_EVT_EXCHANGE_MTU_REQUEST
 case BLE_GATTS_EVT_EXCHANGE_MTU_REQUEST:
    err_code = sd_ble_gatts_exchange_mtu_reply(p_ble_evt->evt.gatts_evt.conn_handle, NRF_BLE_MAX_MTU_SIZE);
    APP_ERROR_CHECK(err_code);
    break; // BLE_GATTS_EVT_EXCHANGE_MTU_REQUEST
#endif

default:
    // No implementation needed.
    break;
}
}

/* @brief Function for dispatching a SoftDevice event to all modules with a SoftDevice event handler. */
/* @details This function is called from the SoftDevice event interrupt handler after a SoftDevice event has been received. */
/* @param[in] p_ble_evt SoftDevice event. */
static void ble_evt_dispatch(ble_evt_t * p_ble_evt) {
    ble_conn_params_on_ble_evt(p_ble_evt);
    ble_nus_on_ble_evt(&m_nus, p_ble_evt);
    on_ble_evt(p_ble_evt);
    ble_advertising_on_ble_evt(p_ble_evt);
    bsp_btn_ble_on_ble_evt(p_ble_evt);
}

/* @brief Function for the SoftDevice initialization. */
/* @details This function initializes the SoftDevice and the BLE event interrupt. */
static void ble_stack_init (void) {
    uint32_t err_code;
    nrf_clock_lf_cfg_t clock_lf_cfg = NRF_CLOCK_LFCLKSRC;
    // Initialize SoftDevice.
    SOFTDEVICE_HANDLER_INIT(&clock_lf_cfg, NULL);
    ble_enable_params_t ble_enable_params;
    err_code = softdevice_enable_get_default_config(CENTRAL_LINK_COUNT, PERIPHERAL_LINK_COUNT, &ble_enable_params);
    APP_ERROR_CHECK(err_code);
    // Check the ram settings against the used number of links
    CHECK_RAM_START_ADDR(CENTRAL_LINK_COUNT,PERIPHERAL_LINK_COUNT);
    // Enable BLE stack.
    #if (NRF_SD_BLE_API_VERSION == 3)
        ble_enable_params.gatt_enable_params.att_mtu = NRF_BLE_MAX_MTU_SIZE;
    #endif
    err_code = softdevice_enable(&ble_enable_params);
    APP_ERROR_CHECK(err_code);
    // Subscribe for BLE events.
    err_code = softdevice_ble_evt_handler_set(ble_evt_dispatch);
    APP_ERROR_CHECK(err_code);
    // enable DCDC to save current
    err_code = sd_power_dcdc_mode_set(NRF_POWER_DCDC_ENABLE);
    APP_ERROR_CHECK(err_code);
}

/* @brief Function for handling events from the BSP module. */
/* @param[in] event Event generated by button press. */
void bsp_event_handler(bsp_event_t event) {
    uint32_t err_code;
    switch (event) {
    case BSP_EVENT_SLEEP:
        sleep_mode_enter();
        break;
    case BSP_EVENT_DISCONNECT:
```
err_code = sd_ble_gap_disconnect(m_conn_handle, BLE_HCI_REMOTE_USER_TERMINATED_CONNECTION);
if (err_code != NRF_ERROR_INVALID_STATE)
{
  APP_ERROR_CHECK(err_code);
}
break;

case BSP_EVENT_WHITELIST_OFF:
  if (m_conn_handle == BLE_CONN_HANDLE_INVALID)
  {
    err_code = ble_advertising_restart_without_whitelist();
    if (err_code != NRF_ERROR_INVALID_STATE)
    {
      APP_ERROR_CHECK(err_code);
    }
  }
  break;

default:
  break;
}

/* @}brief Function for handling app_uart events.
 * @details This function will receive a single character from the app_uart module and append it to a string. The string will be sent over BLE when the last character received was a 'new line' i.e. a '\r'\n' (hex 0x0D) or if the string has reached a length of @ref NUS_MAX_DATA_LENGTH.
*/
/* @{snippet [Handling the data received over UART] */
void uart_event_handle(app_uart_evt_t *p_event)
{
  static uint8_t data_array[BLE_NUS_MAX_DATA_LEN];
  static uint8_t index = 0;
  uint32_t err_code;
  switch (p_event−>evt_type)
  {
    case APP_UART_DATA_READY:
      UNUSED_VARIABLE(app_uart_get(&data_array[index]));
      index++;
      if ((data_array[index − 1] == '\n') || (index >= (BLE_NUS_MAX_DATA_LEN))
      {
        err_code = ble_nus_string_send(&m_nus, data_array, index);
        if (err_code != NRF_ERROR_INVALID_STATE)
        {
          APP_ERROR_CHECK(err_code);
        }
        index = 0;
      }
      break;
    case APP_UART_COMMUNICATION_ERROR:
      APP_ERROR_HANDLER(p_event−>data.error_communication);
      break;
    case APP_UART_FIFO_ERROR:
      APP_ERROR_HANDLER(p_event−>data.error_code);
      break;
    default:
      break;
  }
}/*. @}snippet [Handling the data received over UART] */
/* @}brief Function for initializing the UART module.
*/
/* @{snippet [UART Initialization] */
static void uart_init (void)
{
  uint32_t err_code;
  const app_uart_comm_params_t comm_params =
  {
    RX_PIN_NUMBER, TX_PIN_NUMBER, 0, 0,
    UART_FLOW_CONTROL_DISABLED, false,
    UART_BAUDRATE_BAUDRATE_Baud115200,
  };
  APP_UART_FIFO_INIT(&comm_params,
    UART_RX_BUF_SIZE, UART_TX_BUF_SIZE, uart_event_handle,
    APP_IRQ_PRIORITY_LOW, err_code);
  APP_ERROR_CHECK(err_code);
}/*. @}snippet [UART Initialization] */
/* @}brief Function for initializing the Advertising functionality.
*/
static void advertising_init (void)
{
    uint32_t err_code;
    ble_advdata_t advdata;
    ble_advdata_t scanrsp;
    ble_adv_modes_config_t options;

    // Build advertising data struct to pass into @ref ble_advertising_init.
    memset(&advdata, 0, sizeof(advdata));
    advdata.name_type = BLE_ADVDATA_FULL_NAME;
    advdata.include_appearance = false;
    advdata.flags = BLE_GAP_ADV_FLAGS_LE_ONLY_LIMITED_DISC_MODE;
    memset(&scanrsp, 0, sizeof(scanrsp));
    scanrsp.uuids_complete.uuid_cnt = sizeof(m_adv_uuids) / sizeof(m_adv_uuids[0]);
    scanrsp.uuids_complete.p_uuids = m_adv_uuids;
    memset(&options, 0, sizeof(options));
    options.ble_adv_fast_enabled = true;
    options.ble_adv_fast_interval = APP_ADV_INTERVAL;
    options.ble_adv_fast_timeout = APP_ADV_TIMEOUT_IN_SECONDS;
    err_code = ble_advertising_init (&advdata, &scanrsp, &options, on_adv_evt, NULL);
    APP_ERROR_CHECK(err_code);
}

/* @brief Function for initializing buttons and leds. */
static void buttons_leds_init(bool * p_erase_bonds)
{
    bsp_event_t startup_event;
    uint32_t err_code = bsp_init(BSP_INIT_LED | BSP_INIT_BUTTONS,
                                  APP_TIMER_TICKS(100, APP_TIMER_PRESCALER),
                                  bsp_event_handler);
    APP_ERROR_CHECK(err_code);
    err_code = bsp_btn_ble_init(NULL, &startup_event);
    APP_ERROR_CHECK(err_code);
    *p_erase_bonds = (startup_event == BSP_EVENT_CLEAR_BONDING_DATA);
}

/* @brief Function for placing the application in low power state while waiting for events. */
static void power_manager(void)
{
    uint32_t err_code = sd_app_evt_wait();
    APP_ERROR_CHECK(err_code);
}

/* @brief Undo the changes that we did when advertising has the timeout. */
void wakeup_timer_handler(void * p_context)
{
    app_timer_stop(wakeup_timer_id);
    uint32_t err_code = bsp_init(BSP_INIT_LED | BSP_INIT_BUTTONS,
                                  APP_TIMER_TICKS(100, APP_TIMER_PRESCALER),
                                  bsp_event_handler);
    APP_ERROR_CHECK(err_code);
    err_code = ble_advertising_start(BLE_ADV_MODE_FAST);
    APP_ERROR_CHECK(err_code);
}

/* @brief Application main function. */
int main(void)
{
    uint32_t err_code;
    bool erase_bonds;

    // Initialize.
    APP_TIMER_INIT(APP_TIMER_PRESCALER, APP_TIMER_OP_QUEUE_SIZE, false);
    uart_init ();
    err_code = app_timer_create(&wakeup_timer_id, APP_TIMER_MODE_SINGLE_SHOT, wakeup_timer_handler);
    APP_ERROR_CHECK(err_code);
    buttons_leds_init(&erase_bonds);
    ble_stack_init ();
    ble_stack_config_t params;
    conn_params_init();
    // printf("\r\nUART Start!\n");
    err_code = ble_advertising_start(BLE_ADV_MODE_FAST);
    APP_ERROR_CHECK(err_code);

    // Enter main loop.
    for (;;)
    {
        power_manager();
    }
5 Important notes

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5.1 General customer responsibility

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It has to be clearly pointed out that the possibility of a malfunction of electronic components or failure before the end of the usual lifetime cannot be completely eliminated in the current state of the art, even if the products are operated within the range of the specifications. The same statement is valid for all software sourcecode and firmware parts contained in or used with or for products in the wireless connectivity and sensor product range of Würth Elektronik eiSos GmbH & Co. KG. In certain customer applications requiring a high level of safety and especially in customer applications in which the malfunction or failure of an electronic component could endanger human life or health, it must be ensured by most advanced technological aid of suitable design of the customer application that no injury or damage is caused to third parties in the event of malfunction or failure of an electronic component.

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