

Chapter 4D: BLE Centrals

This chapter introduces you to the Central side of the BLE connection. By the end of this chapter you should be able to create a BLE Central that finds the right BLE Peripheral, connects to it, Reads, Writes and Enables/Handles notifications. It should also be able to perform the GATT Service Discovery Procedure to find the Handles of the Services, Characteristics and Descriptors on the GATT Server.

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4D.1 GAP Roles, the Observer and the Central

In the previous three chapters the focus has been on BLE Peripherals. Instead of dividing the world into Peripheral and Central, it would have been more technically correct to say that Bluetooth Low Energy has four GAP device roles:

- **Broadcaster:** A device that only advertises (e.g. Beacon)
- **Peripheral:** A device that can advertise and be connected to
- **Observer:** A device that passively listens to advertisers (e.g. Beacon Scanner)
- **Central:** A device that can listen to advertisers and create a connection to a Peripheral

So, the previous chapters were really focused on Broadcasters and Peripherals. But what about the other side of the connection? The answer to that question is the focus of this chapter.

4D.2 Scanning

In the previous chapters I talked about how you create different Peripherals that Advertise their existence and some data. How does a Central find this information? And how does it use that information to get connected?

First, you must put the WICED BLE device into scanning mode. You do this with a simple call to `wiced_bt_ble_scan`. This function takes three arguments.

1. The first argument is a `wiced_bt_ble_scan_type_t` which tells the controller to either turn off, scan fast (high duty) or scan slowly (low duty).

```
enum wiced_bt_ble_scan_type_e
{
    BTM_BLE_SCAN_TYPE_NONE,           /**< Stop scanning */
    BTM_BLE_SCAN_TYPE_HIGH_DUTY,      /**< High duty cycle scan */
    BTM_BLE_SCAN_TYPE_LOW_DUTY        /**< Low duty cycle scan */
};
typedef uint8_t wiced_bt_ble_scan_type_t;
```

The actual parameters of scan high/low are configured in the `wiced_bt_cfg_settings_t` structure typically found in `app_bt_cfg.c`.

2. The next argument is a `wiced_bool_t` that tells the scanner to filter or not. If you enable the filter, the scanner will only call you back one time for each unique BD ADDR that it hears even if the advertising packet changes.
3. The final argument is a function pointer to a callback function that looks like this:

```
void myScanCallback(wiced_bt_ble_scan_results_t *p_scan_result, uint8_t *p_adv_data);
```

For example, you may start high duty cycle scanning with filtering like this:

```
wiced_bt_ble_scan( BTM_BLE_SCAN_TYPE_HIGH_DUTY, WICED_TRUE, myScanCallback );
```

Each time that your Central hears an advertisement, it will call your callback with a pointer to a scan result structure with information about the device it just heard, and a pointer to the raw advertising data. The scan result structure simply has the Bluetooth Device Address, the address type, what type of advertisement packet, the RSSI and a flag like this:

```
/** LE inquiry result type */
typedef struct
{
    wiced_bt_device_address_t    remote_bd_addr;    /**< Device address */
    uint8_t                     ble_addr_type;      /**< LE Address type */
    wiced_bt_dev_ble_evt_type_t ble_evt_type;      /**< Scan result event type */
    int8_t                      rssi;
    uint8_t                     flag;
} wiced_bt_ble_scan_results_t;
```

In your advertising callback function you can then parse the advertising data to decide what to do next. The SDK provides you a function called `wiced_bt_ble_check_advertising_data` which can help you find information in the packet. Recall that every advertising packet is broken up into fields that each have a type. The `wiced_bt_ble_check_advertising_data` function will search the advertising packet looking for a field that you specify and then, if it finds that field, will return a pointer to the field and the length (via a pointer). For example, you might have this inside the callback function to search for a Service UUID:

```
uint8_t len;

uint8_t *findServiceUUID = wiced_bt_ble_check_advertising_data(p_adv_data,
    BTM_BLE_ADVERT_TYPE_128SRV_COMPLETE, &len);
```

After making this call, `findServiceUUID` will either be 0 (it didn't find the field) or will be a pointer to the bytes that make up the Service UUID. In addition, `len` will either be 0 or it will be the number of bytes in that field. Remember that the enumeration `wiced_bt_ble_advert_type_e` in the file `wiced_bt_ble.h` has a list of the legal advertising field types.

So, now what? Well consider the two cases in the screenshot from the Advertising Scanner (exercise 4D.6 in this chapter). The results shown in the screenshot are from the devices created in Chapter 4B Exercise 02 and Chapter 4A Exercise 03. There are two different devices advertising, one named "key_pair" and one named "key_adv". You can see the raw bytes of the advertising packet and the decode of those bytes.

COM5 - PuTTY

#	Address	Len	Name	E	I	C	Seen	RSSI	Data
0	E7 AD 3F 8F B1 49	13	key_pair				1s	-54	Decoded Data 02 01 06 09 09 6B 65 79 5F 70 61 69 72 Flags 06 LE General Discoverable BR/EDR Not Supported Complete Name key_pair
1	59 E7 DB 80 FB B9	17	key_adv			X	3s	-53	02 01 06 08 09 6B 65 79 5F 61 64 76 04 FF 31 01 00 Flags 06 LE General Discoverable BR/EDR Not Supported Complete Name key_adv MFG Data Cypress Semiconductor 00
2	61 A5 A6 54 21 A1	14					43s	-96	02 01 1A 0A FF 4C 00 10 05 03 1C 28 C1 44 Flags 1A LE General Discoverable BR/EDR Controller BR/EDR Host MFG Data Apple, Inc. 10 05 03 1C 28 C1 44

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If you were looking for a device named key_pair you could do something like this:

```
uint8_t len;
uint8_t * p_name = wiced_bt_ble_check_advertising_data( p_adv_data,
    BTM_BLE_ADVERT_TYPE_NAME_COMPLETE, &len );

if( p_name && ( len == strlen("key_pair") ) && ! memcmp( "key_pair", p_name, len ) )
{
    WICED_BT_TRACE("Found Matching Device with BD Address: [%B]",
        p_scan_result->remote_bd_addr );
}
```

If you were looking for a device that was advertising the Modus Service UUID you might do the following. Notice that the UUIDs are stored little endian in the advertising packet. This UUID is the one that the key application has – I just copied over the macro from the cycfg_gatt_db.h file. If you created your own application, it will have a different (random) UUID unless you manually enter this value in the configurator.

```
#define __UUID_SERVICE_MODUS 0x0Au, 0x71u, 0x06u, 0xCAu, 0x27u, 0x68u, 0x44u, 0x8Du,
0xECu, 0x47u, 0x76u, 0x07u, 0x6Eu, 0x82u, 0x91u, 0x79u

static const uint8_t modusServiceUUID[]={ __UUID_SERVICE_MODUS };

uint8_t *findServiceUUID = wiced_bt_ble_check_advertising_data(p_adv_data,
    BTM_BLE_ADVERT_TYPE_128SRV_COMPLETE,&len);

if(findServiceUUID && (memcmp(findServiceUUID,modusServiceUUID,len) == 0))
{
    WICED_BT_TRACE("Host = %B Found Service UUID\r\n ", p_scan_result->remote_bd_addr);
}
```

Note: The first argument to the "if" function is there to make sure we have a valid (non-null) pointer returned from the advertising packet.

If you were looking for the Peripheral that was advertising the manufacturer's data with the Cypress manufacturer ID of 0x0131 (which is what "key_adv" is advertising) you might do the following. Again, notice the manufacturer ID is little endian in the advertising packet. Note that we only looked at the first 2 bytes of the manufacturer ID since the third byte changes each time the button is pressed:

```
uint8_t *mfgData = wiced_bt_ble_check_advertising_data(p_adv_data,
    BTM_BLE_ADVERT_TYPE_MANUFACTURER, &len);

if( mfgData && (len > 1) && (mfgData[0] == 0x31) && (mfgData[1] == 0x01 ))
{
    WICED_BT_TRACE("Host = %B length=%d ", p_scan_result->remote_bd_addr, len);
}
```

There are several functions which can be useful in comparing data for when you want to identify a specific device such as (note that you must include string.h to get access to memcmp):

1. memcmp(uint8_t *p1, uint8_t *p2, int size) allows you to compare two blocks of memory. It returns 0 if the two blocks of memory are the same.
2. If you have two variables of type wiced_bt_uuid_t you can compare them with the wiced_bt_util_uuid_cmp function. Like the functions above, it returns 0 if the two UUIDs match.

```
int wiced_bt_util_uuid_cmp(wiced_bt_uuid_t *p_uuid1, wiced_bt_uuid_t *p_uuid2);
```

3. Remember from the Peripherals chapter that WICED_BT_TRACE_ARRAY can be used to print the UUID and mfgData arrays.

4D.3 Connecting, Pairing, and Encrypting

Now that you have found a device that you are interested in what next? First you need to register a GATT event callback. This looks exactly like it does on the peripheral side. Note that you don't need to initialize the GATT database because the Central doesn't contain the database – it's on the Peripheral.

```
wiced_bt_gatt_register(app_bt_gatt_callback);
```

To make a connection you just call wiced_bt_gatt_le_connect:

```
wiced_bool_t wiced_bt_gatt_le_connect(wiced_bt_device_address_t bd_addr,
    wiced_bt_ble_address_type_t bd_addr_type,
    wiced_bt_ble_conn_mode_t conn_mode,
    wiced_bool_t is_direct);
```

The bd_addr and bd_addr_type are passed in to the callback as part of the scan result. The conn_mode is an enumeration with three possible values which determines how fast the connection is established (and how much power is consumed to establish the connection):

```
enum wiced_bt_ble_conn_mode_e
{
    BLE_CONN_MODE_OFF,                /*< Stop initiating */
    BLE_CONN_MODE_LOW_DUTY,           /*< slow connection scan parameter */
    BLE_CONN_MODE_HIGH_DUTY           /*< fast connection scan parameter */
};
```

The final argument should be set to WICED_TRUE. That feature is going to be deprecated.

When the connection has been made, the GATT callback that you registered with `wiced_bt_gatt_register` will be called with the event `GATT_CONNECTION_STATUS_EVT`. The parameter passed to you will be of type `wiced_bt_gatt_connection_status_t` which contains a bunch of information about the connection.

```
typedef struct
{
    uint8_t          *bd_addr;    /**< Remote device address */
    wiced_bt_ble_address_type_t  addr_type; /**< Remote device address type */
    uint16_t         conn_id;    /**< ID of the connection */
    wiced_bool_t     connected;  /**< TRUE/FALSE connected/disconnected */
    wiced_bt_gatt_disconn_reason_t reason; /**< Reason code (see @link
                                         wiced_bt_gatt_disconn_reason_e
                                         wiced_bt_gatt_disconn_reason_t @endlink) */

    wiced_bt_transport_t transport; /**< Transport type of the connection */
    uint8_t          link_role;  /**< Link role on this connection */
} wiced_bt_gatt_connection_status_t;
```

Typically, you would save the `conn_id` so that you can perform Reads and Writes to the Peripheral. If you were going to support multiple connections, you might make a table of connection ID / Bluetooth Address tuples.

Once connected, the Central can initiate pairing (if the devices were not previously bonded). The function is `wiced_bt_dev_sec_bond`:

```
wiced_result_t wiced_bt_dev_sec_bond (wiced_bt_device_address_t bd_addr,
                                     wiced_bt_ble_address_type_t bd_addr_type,
                                     wiced_bt_transport_t transport,
                                     uint8_t pin_len,
                                     uint8_t *p_pin);
```

The transport can be either `BT_TRANSPORT_BR_EDR` (for Classic) or `BT_TRANSPORT_LE` (for BLE). The last two arguments are only for legacy pairing modes, so just use 0 for `pin_len` and NULL for `p_pin`.

Remember that some Characteristic values can only be read or written once the device is paired. This is determined by the GATT Characteristic Permissions (e.g. `LEGATTDB_PERM_AUTH_READABLE` or `LEGATTDB_PERM_AUTH_WRITABLE`).

If you previously saved bonding information on both the Peripheral and Client, then you don't need to initiate pairing on subsequent connections. In that case instead of `wiced_bt_dev_sec_bond` you just need to enable encryption by calling `wiced_bt_dev_set_encryption`:

```
wiced_result_t wiced_bt_dev_set_encryption (wiced_bt_device_address_t bd_addr,
                                           wiced_bt_transport_t transport,
                                           void *p_ref_data);
```

The transport is again either `BT_TRANSPORT_BR_EDR` (for Classic) or `BT_TRANSPORT_LE` (for BLE). The last argument is a pointer to an enumeration of type `wiced_bt_ble_sec_action_type_t` which returns the encryption status. The enumeration is:

```
/** LE encryption method */
enum
{
    BTM_BLE_SEC_NONE,           /**< No encryption */
    BTM_BLE_SEC_ENCRYPT,        /**< encrypt the link using current key */
    BTM_BLE_SEC_ENCRYPT_NO_MITM, /**< encryption without MITM */
};
```

```

    BTM_BLE_SEC_ENCRYPT_MITM          /**< encryption with MITM*/
};
typedef uint8_t wiced_bt_ble_sec_action_type_t;

```

To summarize, the Client would typically do something like this after making a connection:

```

#define VSID_KEYS_START                (WICED_NVRAM_VSID_START)
#define VSID_NUM_KEYS                  (4)
#define VSID_KEYS_END                  (VSID_KEYS_START+VSID_NUM_KEYS)

wiced_bt_device_link_keys_t temp_keys;
wiced_bt_ble_sec_action_type_t encryption_type = BTM_BLE_SEC_ENCRYPT;

for ( i = VSID_KEYS_START; i < VSID_KEYS_END; i++ ) //Search NVRAM for keys
{
    bytes_read = wiced_hal_read_nvr( i, sizeof( temp_keys ), //Attempt to read NVRAM
                                     (uint8_t *)&temp_keys, &result );
    if ( result == WICED_SUCCESS ) // NVRAM had something at this location
    {
        if ( memcmp( temp_keys.bd_addr, bd_address, BD_ADDR_LEN ) == 0 )
        {
            isBonded = WICED_TRUE; // We found keys for the Peripheral's BD Address
        }
    }
}

if ( isBonded ) /* Device is bonded so just need to enable encryption */
{
    status = wiced_bt_dev_set_encryption( p_peer_info->peer_addr,
                                         p_peer_info->transport,
                                         &encryption_type );
    WICED_BT_TRACE( "wiced_bt_dev_set_encryption %d \n", status );
}
else /* Device not bonded so we need to pair */
{
    status = wiced_bt_dev_sec_bond( p_peer_info->peer_addr,
                                   p_peer_info->addr_type,
                                   p_peer_info->transport, 0, NULL );
    WICED_BT_TRACE( "wiced_bt_dev_sec_bond %d \n", status );
}

```

When you want to disconnect, just call `wiced_bt_gatt_disconnect` with the connection ID as a parameter. Note that the connect function has "le" in the name but the disconnection function does not!

4D.4 Attribute Protocol & More GATT Procedures

In the previous chapters I introduced you to the Peripheral side of several GATT Procedures. Specifically, Read, Write and Notify. Moreover, in those chapters you learned how to create WICED firmware to respond to those requests. You will recall that each of those GATT Procedures are mapped into one or more Attribute requests. Here is a list of all the Attribute requests with the original request and the applicable response.

Note that the request can be initiated by either the Client or Server depending on the operation. For example, a Write is initiated by the GATT Client while a Notification is initiated by the GATT Server.

BT Spec * Chap Ref	Request	Request Data	BT Spec * Chap Ref	Response	Response Data
			3.4.1.1 N/A	Error Response	Request Op Code in Error Attribute Handle in Error Error Code
3.4.2.1 N/A	Exchange MTU	Client Rx MTU	3.4.2.2 N/A	Exchange MTU response	Server Rx MTU
3.4.3.1 4D.4.9	Find Information	Starting Handle Ending Handle	3.4.3.2 4D.4.9	Find Information Response	Handles Attribute Type UUIDs
3.4.3.3 4D.4.7	Find by Type Value	Starting Handle Ending Handle Attribute Type Attribute Value	3.4.3.4 4D.4.60	Find by Type Value Response	Start Handle End of Group Handle
3.4.4.1 0	Read by Type	Starting Handle Ending Handle Attribute Type UUID	3.4.4.2 0	Read by Type Response	Handle Value Pairs
3.4.4.3 4D.4.1	Read	Handle	3.4.4.4 4A	Read Response	Handle, Value
3.4.4.5 N/A	Read Blob	Handle, Offset	3.4.4.6 N/A	Read Blob Response	Handle, Data
3.4.4.7 N/A	Read Multiple	Handles	3.4.4.8 N/A	Read Multiple Response	One response with all values concatenated
3.4.4.9 4D.4.6	Read by Group Type	Starting Handle Ending Handle Attribute Group Type UUID	3.4.4.10 4D.4.6	Read by Group Type Response	For each match: Handle, Value Handle of last Attribute in Group
3.4.5.1 4D.4.3	Write	Handle, Value	There is no Server response to a Write.		
3.4.5.3 4D.4.3	Write Command	Handle, Value	3.4.5.2 4A	Write Response	Response code 0x1E Or Error Response
3.4.5.4 N/A	Signed Write Command	Handle, Value, Signature	3.4.5.2 4A	Write Response	Response code 0x1E Or Error Response
3.4.6.1 N/A	Prepare Write	Handle Offset Value	3.4.6.2 N/A	Prepare Write Response	Handle Offset Value
3.4.6.3 N/A	Execute Write	Flags (0-cancel, 1-write)	3.4.6.4 N/A	Execute Write Response	Response code 0x19 Or Error Response
3.4.7.1 4B	Notification	Handle, Value	There is no Client response to a Notification, but you can read about what happens on the Client side in 0		
3.4.7.2 4B	Indication	Handle, Value	3.4.7.3 0	Handle Value Confirmation	Response code 0x1E Or Error Response

* BT Spec references are from Volume 3, Part F (Attribute Protocol). Additional details on the GATT procedures that use the ATT protocols can be found in Volume 3, Part G (Generic Attribute Profile).

This leads us to some obvious questions: What happens with Read, Write and Notify on the GATT Client side of a connection? And what about these other operations?

4D.4.1 GATT Library

There is a library of functions available to simplify setting up and performing various GATT operations such as Reading Characteristic Values, setting Characteristic Descriptor values and doing Service Discovery. To use these functions, you need to add the GATT utilities library to your application.

In the makefile:

1. Add a component entry:

```
COMPONENTS += gatt_utils_lib
```

2. Add a new line below the existing SEARCH_LIBS_AND_INCLUDES variable:

```
SEARCH_LIBS_AND_INCLUDES += $(CY_SHARED_PATH)/dev-kit/libraries/btsdk-ble
```

Then you need to include the header file at the top of your C file:

```
#include "wiced_bt_gatt_util.h"
```

4D.4.2 GATT Client Read

To initiate a read of the value of a Characteristic you need to know two things, the Handle of the Characteristic and the connection ID. To execute a read you just call:

```
wiced_bt_util_send_gatt_read_by_handle( conn_id, handle );
```

This function call will cause the Stack to send a read request to the GATT Server. After some time, you will get a callback in your GATT event handler with the event code GATT_OPERATION_CPLT_EVENT. The callback parameter can then be cast into a wiced_bt_gatt_operation_complete_t. This structure has everything you need. Specifically:

```
/** Response to read/write/disc/config operations (used by GATT_OPERATION_CPLT_EVT
notification) */
typedef struct
{
    uint16_t          conn_id;           /**< ID of the connection */
    wiced_bt_gatt_optype_t op;           /**< Type of operation completed */
    wiced_bt_gatt_status_t status;       /**< Status of operation */
    wiced_bt_gatt_operation_complete_rsp_t response_data; /**< Response data */
} wiced_bt_gatt_operation_complete_t;
```

This same event is used to handle many of the responses from a GATT Server. Exactly which response can be determined by the wiced_bt_gatt_optype_t which is just an enumeration of operations. For instance, 0x02 means you are getting the response from a read.

```
enum wiced_bt_gatt_optype_e
{
    GATTC_OPTYPE_NONE           = 0,    /**< None */
    GATTC_OPTYPE_DISCOVERY      = 1,    /**< Discovery */
    GATTC_OPTYPE_READ           = 2,    /**< Read */
    GATTC_OPTYPE_WRITE          = 3,    /**< Write */
    GATTC_OPTYPE_EXE_WRITE      = 4,    /**< Execute Write */
    GATTC_OPTYPE_CONFIG         = 5,    /**< Configure */
    GATTC_OPTYPE_NOTIFICATION   = 6,    /**< Notification */
    GATTC_OPTYPE_INDICATION     = 7,    /**< Indication */
}
```

```
};
```

The `wiced_bt_gatt_status_t` is an enumeration of different error codes from the enumeration `wiced_bt_gatt_status_e` which was introduced in Chapter 4A. As a reminder, the first few values are:

```
enum wiced_bt_gatt_status_e
{
    WICED_BT_GATT_SUCCESS                = 0x00,          /**< Success */
    WICED_BT_GATT_INVALID_HANDLE        = 0x01,          /**< Invalid Handle */
    WICED_BT_GATT_READ_NOT_PERMIT       = 0x02,          /**< Read Not Permitted */
    WICED_BT_GATT_WRITE_NOT_PERMIT      = 0x03,          /**< Write Not permitted */
    WICED_BT_GATT_INVALID_PDU           = 0x04,          /**< Invalid PDU */
}
```

The last piece is the response data, `wiced_bt_gatt_operation_complete_rsp_t` which contains the handle and an attribute value structure which contains the actual GATT data along with information about it.

```
typedef union
{
    wiced_bt_gatt_data_t    att_value;    /**< Response data for read operations
                                           (initiated using #wiced_bt_gatt_send_read) */
    uint16_t                mtu;          /**< Response data for configuration
                                           operations */
    uint16_t                handle;       /**< Response data for write operations
                                           (initiated using #wiced_bt_gatt_send_write) */
} wiced_bt_gatt_operation_complete_rsp_t; /**< GATT operation complete response type */
```

The attribute value structure containing the GATT data looks like this:

```
/** Response data for read operations */
typedef struct
{
    uint16_t                handle;       /**< handle */
    uint16_t                len;          /**< length of response data */
    uint16_t                offset;       /**< offset */
    uint8_t                 *p_data;     /**< attribute data */
} wiced_bt_gatt_data_t;
```

These structures look a bit overwhelming, but you can easily use this information to find out what happened. Here is an example of how you might deal with this callback to print out the response and all the raw bytes of the data that were sent.

```
case GATT_OPERATION_CPLT_EVT:

    // When you get something back from the peripheral... print it out.. the data
    WICED_BT_TRACE("Event Complete Conn=%d Op=%d status=0x%X Handle=0x%X len=%d Data=",
        p_data->operation_complete.conn_id,
        p_data->operation_complete.op,
        p_data->operation_complete.status,
        p_data->operation_complete.response_data.handle,
        p_data->operation_complete.response_data.att_value.len);

    for(int i=0;i<p_data->operation_complete.response_data.att_value.len;i++)
    {
        WICED_BT_TRACE("%02X ",
            p_data->operation_complete.response_data.att_value.p_data[i]);
    }
    WICED_BT_TRACE("\r\n");
    break;
```

4D.4.3 GATT Client Write and Write Command

In order to send a GATT Write all you need to do is make a structure of type `wiced_bt_gatt_value_t`, setup the handle, offset, length, authorization and value; then call `wiced_bt_gatt_send_write`. Here is an example:

```
wiced_bt_gatt_value_t *p_write = ( wiced_bt_gatt_value_t* )wiced_bt_get_buffer( sizeof(
wiced_bt_gatt_value_t ) + sizeof(myData)-1);
if ( p_write )
{
    p_write->handle    = myHandle;
    p_write->offset     = 0;
    p_write->len        = sizeof(myData);
    p_write->auth_req   = GATT_AUTH_REQ_NONE;
    memcpy(p_write->value, &myData, sizeof(myData));

    wiced_bt_gatt_send_write ( conn_id, GATT_WRITE, p_write );

    wiced_bt_free_buffer( p_write );
}
```

The second argument to `wiced_bt_gatt_send_write` function can either be `GATT_WRITE` or `GATT_WRITE_NO_RSP` depending on whether you want a response from the server or not.

The one trick is that the length of the structure is variable with the length of the data. In the above example, you allocate a block big enough to hold the structure + the length of the data minus 1 using `wiced_bt_get_buffer`. Then use a pointer to fill in the data. The buffer is freed up once the write is done.

Note that the `wiced_bt_get_buffer` and `wiced_bt_free_buffer` functions require that you include `wiced_memory.h` in the C file.

If you asked for a write with response (i.e. `GATT_WRITE`), sometime after you call the `wiced_bt_gatt_send_write` you will get a GATT callback with the event code `GATT_OPERATION_CPLT_EVT`. You can then figure out if the write was successful by checking to see if you got a Write Response or an Error Response (with the error code from the `wiced_bt_gatt_status_e` enumeration).

Don't forget the you can only issue one Read/Write at a time and that you cannot send the next Read/Write until the last one is finished.

4D.4.4 GATT Client Notify and Indicate

To register for Notifications and Indications, the Client just needs to write to the CCCD for the Characteristic of interest. There is a utility function that simplifies the process of writing the Descriptor called `wiced_bt_util_set_gatt_client_config_descriptor`. The function takes three arguments:

1. The connection ID
2. The handle of the Descriptor
3. The value to write

For a CCCD, the LSB (bit 0) is set to 1 for Notifications, and bit 1 is set to 1 for Indications. That is:

```
/** characteristic descriptor: client configuration value */
enum wiced_bt_gatt_client_char_config_e
{
    GATT_CLIENT_CONFIG_NONE           = 0x0000,      /**< No notifications or indications */
    GATT_CLIENT_CONFIG_NOTIFICATION = 0x0001,      /**< Send notifications */
    GATT_CLIENT_CONFIG_INDICATION    = 0x0002      /**< Send indications */
};
```

When the GATT Server initiates a Notify or an Indicate you will get a GATT callback with the event code set as `GATT_OPERATION_CPLT_EVT`. You will see that the Operation value is `GATTC_OPTYPE_NOTIFICATION` or `GATTC_OPTYPE_INDICATE` and the value is just like the Read Response. In the case of Indicate you can return `WICED_BT_GATT_SUCCESS` which means the Stack will return a Handle Value Confirmation to the Client, or you can return something other than `WICED_BT_GATT_SUCCESS` in which case the Stack sends an Error Response with the code that you choose from the `wiced_bt_gatt_status_e` enumeration. Remember from Chapter 4A that the (partial) list of available return values is:

```
enum wiced_bt_gatt_status_e
{
    WICED_BT_GATT_SUCCESS           = 0x00,      /**< Success */
    WICED_BT_GATT_INVALID_HANDLE    = 0x01,      /**< Invalid Handle */
    WICED_BT_GATT_READ_NOT_PERMIT    = 0x02,      /**< Read Not Permitted */
    WICED_BT_GATT_WRITE_NOT_PERMIT   = 0x03,      /**< Write Not permitted */
    WICED_BT_GATT_INVALID_PDU        = 0x04,      /**< Invalid PDU */
    WICED_BT_GATT_INSUF_AUTHENTICATION = 0x05,      /**< Insufficient Authentication */
    WICED_BT_GATT_REQ_NOT_SUPPORTED   = 0x06,      /**< Request Not Supported */
    WICED_BT_GATT_INVALID_OFFSET      = 0x07,      /**< Invalid Offset */
    WICED_BT_GATT_INSUF_AUTHORIZATION = 0x08,      /**< Insufficient Authorization */
    WICED_BT_GATT_PREPARE_Q_FULL      = 0x09,      /**< Prepare Queue Full */
    WICED_BT_GATT_NOT_FOUND           = 0x0a,      /**< Not Found */
    WICED_BT_GATT_NOT_LONG            = 0x0b,      /**< Not Long Size */
    WICED_BT_GATT_INSUF_KEY_SIZE      = 0x0c,      /**< Insufficient Key Size */
    WICED_BT_GATT_INVALID_ATTR_LEN    = 0x0d,      /**< Invalid Attribute Length */
    WICED_BT_GATT_ERR_UNLIKELY        = 0x0e,      /**< Error Unlikely */
    WICED_BT_GATT_INSUF_ENCRYPTION    = 0x0f,      /**< Insufficient Encryption */
    WICED_BT_GATT_UNSUPPORT_GRP_TYPE  = 0x10,      /**< Unsupported Group Type */
    WICED_BT_GATT_INSUF_RESOURCE      = 0x11,      /**< Insufficient Resource */
}
```

4D.4.5 GATT Group

There is one last GATT concept that needs to be introduced to understand the next GATT Procedures. That is the Group. A Group is a range of handles starting at a Service, Service Include or a Characteristic and ending at the last Handle that is associated with the Group. To put it another way, a Group is all of the rows in the GATT database that logically belong together. For instance, in the GATT database below, the Service Group for <<Generic Access>> starts at Handle 0x0001 and ends at 0x0005.

4D.4.6 GATT Client Read by Group Type

The GATT Client Read by Group Type request takes as input a search starting Handle, search ending Handle and Group type. It outputs a list of tuples with the Group start Handle, Group end Handle, and value. This request can only be used for a “Grouping Type” meaning, <<Service>>, <<Included Service>> and <<Characteristic>>.

Note, anything inside double angle brackets << >> indicates a Bluetooth SIG defined UUID. For example, <<Primary Service>> is defined by the SIG to be 0x2800.

Consider this GATT database for a peripheral with a service called Modus that contains two characteristics; Counter and RGBLED (which happens to be the application you will control from your central device in this chapter’s exercises).

Handle	Type	Value
0x0001	<<Primary Service>>	<<Generic Access>>
0x0002	<<Characteristic>>	0x02, 0x0003, <<Device Name>>
0x0003	<<Device Name>>	key_p
0x0004	<<Characteristic>>	0x02, 0x0005, <<Appearance>>
0x0005	<< Appearance>>	0x0000
0x0006	<<Primary Service>>	<<Generic Attribute>>
0x0007	<<Primary Service>>	__UUID_SERVICE_MODUS
0x0008	<<Characteristic>>	0x0A, 0x0009, __UUID_CHARACTERISTIC_MODUS_RGBLED
0x0009	__UUID_CHARACTERISTIC_MODUS_RGBLED	RGB LED value
0x000A	<<Characteristic>>	0x1A, 0x000B, __UUID_CHARACTERISTIC_MODUS_COUNTER
0x000B	__UUID_CHARACTERISTIC_MODUS_COUNTER	Counter Value
0x000C	<<CCCD>>	0x0000 (notify off) or 0x0001 (notify on)

Remember from chapter 4A that the type and values for different attributes are:

Attribute	Type	Value
Service	<<Primary Service>> or <<Secondary Service>>	Service UUID
Characteristic	<<Characteristic>>	Properties, Handle to the Value, Characteristic UUID
Characteristic Value	Characteristic UUID	Characteristic Value

In the database above if you input search start Handle=0x0001, search end Handle=0xFFFF and Group Type = <<Service>> you would get as output:

Group Start Handle	Group End Handle	UUID
0x0001	0x0005	<<Generic Access>>
0x0006	0x0006	<<Generic Attribute>>
0x0007	0x000C	__UUID_SERVICE_MODUS

In words, you receive a list of all the Service UUIDs with the start Handle and end Handle of each Service Group.

4D.4.7 GATT Client Find by Type Value

The GATT Client "Find by Type Value" request takes as input the search starting Handle, search ending Handle, Attribute Type and Attribute Value. It then searches the Attribute database and returns the starting and ending Handles of the Group that match that Attribute Type and Attribute Value. This function was put into GATT specifically to find the range of Handles for a specific Service.

Consider the example above. If your input to the "Find by Type Value" was starting handle=0x0001, ending handle=0xFFFF, Type=<<Service>> and Value=__UUID_SERVICE_MODUS the output would be:

Group Start Handle	Group End Handle
0x0007	0x000C

This function cannot be used to search for a specific Characteristic because the Attribute value of a Characteristic declaration cannot be known a-priori. This is because the Characteristic Properties and Characteristic Value Attribute Handle (which are part of the Attribute Value) are not known up front. As a reminder, here is the Characteristic declaration:

Attribute Handle	Attribute Types	Attribute Value			Attribute Permissions
0xNNNN	0x2803–UUID for «Characteristic»	Characteristic Properties	Characteristic Value Attribute Handle	Characteristic UUID	Read Only, No Authentication, No Authorization

4D.4.8 GATT Client Read by Type

The GATT Client "Read by Type" request takes as input the search starting Handle, search ending Handle and Attribute Type. It outputs a list of Handle value pairs. In the example above if you entered the search starting Handle=0x0007, search ending Handle=0x000C and Type=<<Characteristic>> you would get as output:

Characteristic Handle	Value Handle	UUID	GATT Permission
0x08	0x09	__UUID_CHARACTERISTIC_MODUS_RGBLED	0x0A
0x0A	0x0B	__UUID_CHARACTERISTIC_MODUS_COUNTER	0x0A

In words, you get back a list of the Characteristic Handles, the Handles of the Values, the UUIDs, and the GATT Permissions.

4D.4.9 GATT Client Find Information

The input to the GATT Client "Find Information Request" is simply a search starting Handle and a search ending Handle. The GATT Server then responds with a list of every Handle in that range, and the Attribute type of the handle. Notice that this is the only GATT procedure that returns the Attribute Type.

If you execute a GATT Client Find Information with the handle range set to 0x0005→0x0005 you will get a response of:

Handle	Attribute Type
0x0005	<<Appearance>>

In words, the attribute type that is associated with the Characteristic handle 0x0005.

4D.5 GATT Procedure: Service Discovery

Given that all transactions between the GATT Client and GATT Server use the “Handle” instead of the UUID, one huge question left unanswered is how do you find the Handles for the different Services, Characteristics and Descriptors on the GATT Server? A very, very bad answer to that question is that you hardcode the handles into the GATT Client (although some devices with custom applications do just that). A much better answer is that you do Service Discovery. The phrase Service Discovery includes discovering all the Attributes of a device including Services, Characteristics and Descriptors. This is done using the GATT Procedures that were introduced in sections just above: Read by Group Type, Find by Type Value, Read by Type and Find Information.

4D.5.1 Service Discovery Algorithm

The steps in the Service discovery algorithm are:

1. Do one of the following:
 - a. Discover all the Services using Read by Group Type which gives you the UUID and Start and End Handles of all the Service Groups.
 - b. Discover one specific Service by using Find by Type Value which gives you the Start and End Handles of the specified Service Group.
2. For each Service Group discover all the Characteristics using Read by Type with the Handle range of the Service Group or Groups that you discovered in step (1). This gives you the you the Characteristic Handles, Characteristic Value Handles, UUIDs, and Permissions of each Characteristic.
3. Using the Characteristic Handles from (2) you can then calculate the start and end Handle ranges of each of the Descriptors for each Characteristic.
 - a. The range for a given Characteristic starts at the next handle after the Characteristic's Value Handle and ends either at the end of the Service group (if it's the last Characteristic in the Service group) or just before the next Characteristic Handle (if it isn't the last Characteristic in the Service group).
4. Using the ranges from (3) discover the Descriptors using the GATT Procedure Find Information. This gives you the Attribute type of each Descriptor.

4D.5.2 WICED Service Discovery

The GATT utilities library that we introduced earlier has a Service discovery API that can discover Services, Characteristics and Descriptors:

```
wiced_bt_gatt_status_t wiced_bt_gatt_send_discover (uint16_t conn_id,
                                                    wiced_bt_gatt_discovery_type_t discovery_type,
                                                    wiced_bt_gatt_discovery_param_t *p_discovery_param );
```

The discovery type is an enumeration (note that GATT_DISCOVER_MAX is not a legal parameter):

```
enum wiced_bt_gatt_discovery_type_e
{
    GATT_DISCOVER_SERVICES_ALL = 1,                /**< discover all services */
    GATT_DISCOVER_SERVICES_BY_UUID,                /**< discover service by UUID */
}
```



```

GATT_DISCOVER_INCLUDED_SERVICES,      /**< discover an included service within a service */
GATT_DISCOVER_CHARACTERISTICS,        /**< discover characteristics of a service*/
GATT_DISCOVER_CHARACTERISTIC_DESCRIPTOR, /**< discover characteristic descriptors */
GATT_DISCOVER_MAX                      /* maximum discovery types */
};

```

The discovery parameter contains:

```

typedef struct
{
    wiced_bt_uuid_t uuid;      /**< Service or Characteristic UUID */
    uint16_t s_handle;         /**< Start handle for range to search */
    uint16_t e_handle;         /**< End handle for range to search */
} wiced_bt_gatt_discovery_param_t;

```

After you call this function, the stack will issue the correct GATT Procedure. Then, each time the GATT Server responds with some information you will get a GATT callback with the event type set to GATT_DISCOVERY_RESULT_EVT. The event parameter can then be decoded using a set of macros provided by the SDK.

```

/*****
 * Macros for parsing results GATT discovery results
 * (while handling GATT_DISCOVERY_RESULT_EVT)
 *****/

/* Discovery type: GATT_DISCOVER_SERVICES_ALL or GATT_DISCOVER_SERVICES_BY_UUID */
#define GATT_DISCOVERY_RESULT_SERVICE_START_HANDLE(p_event_data)
#define GATT_DISCOVERY_RESULT_SERVICE_END_HANDLE(p_event_data)
#define GATT_DISCOVERY_RESULT_SERVICE_UUID_LEN(p_event_data)
#define GATT_DISCOVERY_RESULT_SERVICE_UUID16(p_event_data)
#define GATT_DISCOVERY_RESULT_SERVICE_UUID32(p_event_data)
#define GATT_DISCOVERY_RESULT_SERVICE_UUID128(p_event_data)

/* Discovery type: GATT_DISCOVER_CHARACTERISTIC_DESCRIPTOR */
#define GATT_DISCOVERY_RESULT_CHARACTERISTIC_DESCRIPTOR_UUID_LEN(p_event_data)
#define GATT_DISCOVERY_RESULT_CHARACTERISTIC_DESCRIPTOR_UUID16(p_event_data)
#define GATT_DISCOVERY_RESULT_CHARACTERISTIC_DESCRIPTOR_UUID32(p_event_data)
#define GATT_DISCOVERY_RESULT_CHARACTERISTIC_DESCRIPTOR_UUID128(p_event_data)
#define GATT_DISCOVERY_RESULT_CHARACTERISTIC_DESCRIPTOR_VALUE_HANDLE(p_event_data)

/* Discovery type: GATT_DISCOVER_CHARACTERISTICS */
#define GATT_DISCOVERY_RESULT_CHARACTERISTIC_VALUE_HANDLE(p_event_data)
#define GATT_DISCOVERY_RESULT_CHARACTERISTIC_UUID_LEN(p_event_data)
#define GATT_DISCOVERY_RESULT_CHARACTERISTIC_UUID16(p_event_data)
#define GATT_DISCOVERY_RESULT_CHARACTERISTIC_UUID32(p_event_data)
#define GATT_DISCOVERY_RESULT_CHARACTERISTIC_UUID128(p_event_data)

```

There really should be a macro called GATT_DISCOVERY_RESULT_CHARACTERISTIC_HANDLE but for some reason, it isn't in WICED (yet). Therefore, when you want to get a Characteristic's Handle during Characteristic Discovery in your callback, you will have to use something like this:

```

p_data->discovery_result.discovery_data.characteristic_declaration.handle

```

When the discovery is complete you will get one more GATT callbacks with the event type set to GATT_DISCOVERY_CPLT_EVT.



Your firmware would typically be a state machine that would sequence through the Service, Characteristic and Descriptor discoveries as the GATT_DISCOVERY_CPLT_EVT is completed.

4D.6 Running a GATT Server

Although somewhat uncommon, there is no reason why a BLE Central cannot run a GATT Server. In other words, all combinations of GAP Peripheral/Central and GATT Server/Client are legal. An example of this might be a TV that has a BLE remote control. Recall that the device that needs to save power is always the Peripheral, in this case the Remote Control. However, the TV is the thing being controlled, so it would have the GATT database remembering things like channel, volume, etc.

The firmware that you write on a Central to run a GATT database is EXACTLY the same as on a Peripheral.

4D.7 Exercises

The exercises in this chapter require two kits - a peripheral and a central. You can use another CYW920819EVB-02 kit (Arduino style) or CYBT-213043-MESH kit (custom form factor) for the PERIPHERAL device. Always use a CYW920819EVB-02 kit for the central.

The peripheral application is a combination of the exercises from previous chapters. It advertises the device name and a service UUID. Once connected there is an LED characteristic that can be read and written without authentication. Note that on the MESH kit the LED is an RGB LED that takes a value from 0 (off) to 7 (white), while the EVB kit only has a single-color LED and any non-zero value turns it on. A counter characteristic, which is controlled by the button on the peripheral, requires pairing to be read and supports notifications.

Exercise - 4D.1 Make an Observer

In this exercise you will build an observer that will listen to all the BLE devices that are broadcasting and will print out the BD Address of each device that it finds. To create this application, follow these steps:

1. Begin by programming your peripheral kit with the provided application. If you don't already have a 2nd kit to use as the peripheral, get one from an instructor. It will either be a CYBT-213043-MESH kit or a second CYW920819EVB-02 kit.
 - a. Make sure only the kit that you intend to use as a peripheral is plugged into your computer.
 - b. Create a new application called **ch4d_ex00_peripheral** from the template in: `templates/ch4d_ex00_peripheral`.
 - i. Hint: Make sure you select the **CYBT-213043-MESH** BSP during new project creation if you are using the MESH kit for the peripheral.
 - c. Use the Bluetooth Configurator to change the device name to `<init>_p`.
 - d. Build and program the kit.
 - e. Use the PC version of CySmart to test the application.
 - i. Connect and open the GATT database browser.
 - ii. Write a number between 0 and 7 to control the RGBLED.

Note: If you are using a CYW920819EVB-02 for the peripheral, there is no RGB and numbers 1 through 7 just turn on the LED.

 - iii. Check that you can't enable notifications (not authenticated).
 - iv. Pair the device.
 - v. Enable notifications and check that the button changes the Counter.
2. Unplug your Peripheral so that you don't accidentally re-program it with the Central application.
 - a. Hint: You should not need to re-program this kit again and so, if possible, plug it into a charger instead of your computer.
3. Create a new application called **ch4d_ex01_observer** from the template in `templates/ch4d_ex01_observer`.

4. In app.c, make a callback function to process the scanned advertising packets which just prints out the BD Address of the devices that it finds. This function declaration should look like this:

```
void myScanCallback( wiced_bt_ble_scan_results_t *p_scan_result, uint8_t *p_adv_data );
```

Hint: Remember you can use the format code %B in WICED_BT_TRACE to print a BD Address.

5. Add a call to wiced_bt_ble_scan in the BTM_ENABLED event with a function pointer to the callback function you created in the previous step. Enable filtering so that each new device only shows up once – otherwise you will see a LOT of packets from everyone's Peripheral.
6. Build and Program to your kit.
7. Open a terminal window.
8. If it is not already powered from a charger, plug in the kit programmed with your Peripheral application.
9. Open CySmart on your PC or Android Phone to find the BD Address of your Peripheral. You can also look at the UART terminal of the peripheral to find its address.
10. Look for the same BD Address in the list of devices printed by your Central.

Exercise - 4D.2 Read the Device Name to Show Only Your Peripheral Device's Info

In this exercise you will extend the previous exercise so that it examines the advertising packet to find the device name. It will only list your device instead of all devices. It will also look for the Modus Service UUID.

1. If necessary, unplug your Peripheral so that you don't accidentally re-program it.
2. Create a new application called **ch4d_ex02_observer_mydev** from the template in templates/ch4d_ex02_observer_mydev or import from your previous exercise.
3. Change the scanner callback function so that it looks at the advertising packet. Find and print out the BD Address only of devices that match your Peripheral's Device Name.
 - a. Hint: You can use the function `wiced_bt_ble_check_advertising_data` to look at the advertising packet and find fields of type `wiced_bt_ble_advert_type_t`. If there is a field that matches it will return a pointer to those bytes and a length.
 - b. Hint: You can use `memcmp` to see if the fields match what you are looking for.
4. For the advertising packet from your peripheral, search for a Service UUID and print its value to the terminal.
 - a. Hint: Remember the function `WICED_BT_TRACE_ARRAY` can be used to print out the value of an array much easier than using `WICED_BT_TRACE`.
5. Program your application to your Central.
6. Plug in your Peripheral and check to see if it is found. It should print:
 - a. Device Name of your Peripheral
 - b. BD Address
 - c. UUID for the Modus Service – check that this matches the value of `__UUID_SERVICE_MODUS` in `cycfg_gatt_db.h` in the `ch4d_ex00_peripheral` application.
7. Use CySmart on your PC or your phone to verify that the BD Address matches.

Exercise - 4D.3 Update to Connect to Your Peripheral Device & Turn ON/OFF the LED

In this exercise, you will modify the previous exercise to connect to your Peripheral once it finds it. We will decide what to connect to based on your Peripheral's Device Name. In real-world applications, it would be more common to search for a Service UUID or Manufacturer Data but during class you will need to use the Device Name since there will be a lot of devices with the same Service and Manufacturer Data.

Once connected, you will be able to send values to the LED Characteristic to turn the LED off/on.

To simplify the application, you will hardcode the handle, but in the upcoming exercises you will add Service discovery.

Since there are a lot of additions to be made, we will do them in 3 parts and will test each one along the way.

The steps are as follows:

1. Create a new application called **ch4d_ex03_connect** from the template in templates/ch4d_ex03_connect.
2. The template includes a keyboard interface called `uart_rx_callback()` that reads in and handles single key commands. Uncomment the code in the `BTM_ENABLED_EVT` to install the PUART receive handler. The callback function handles these key presses:
 - a. `?`: print out help
 - b. `s`: turn on scanning
 - c. `S`: turn off scanning
3. Update the UART Rx callback function to add the appropriate `wiced_bt_ble_scan` commands to start/stop scanning.
4. Remove the call to `wiced_bt_ble_scan` from the `BTM_Enabled` event.
5. Test Part 1: Unplug your Peripheral (if needed), program your Central, and plug your Peripheral back in.
6. Verify that the keyboard interface works and that s/S turns scanning on and off.
7. In the `app_bt_cfg.c` file, find the GATT configuration entry for `client_max_links`. Change the value from 0 to 1. If you don't change this setting, the connection will not be allowed.
8. Update your scan callback function to connect to the Peripheral when it finds one that it recognizes by calling `wiced_bt_gatt_le_connect`.
 - a. Note: As mentioned previously, you will need to use the Device Name of the Peripheral here so that it will connect to your device. If you used the UUID or Manufacturer Data, it would connect to the first matching device it found which would almost certainly belong to another student.
9. After making the connection, turn off scanning.
10. The template also includes a simple GATT callback function. Register this callback function in the `BTM_ENABLED` event with function `wiced_bt_gatt_register`.
11. Add a global variable `uint16_t` to save the connection id.

12. In the GATT callback when you get a GATT_CONNECTION_STATUS_EVT figure out if it is a connect or a disconnect. Save the connection id to your global variable on a connect and set it to 0 on a disconnect. Print out a message when a connect or disconnect happens.
13. Add a 'd' command to the UART interface to call the disconnect function.
 - a. Hint: remember that the disconnect function does not have "le" in its name.
14. In the management callback add a case for BTM_PAIRING_DEVICE_LINK_KEYS_REQUEST_EVT. Because we are not pairing set the status variable to return WICED_BT_ERROR.
15. Test Part 2: Unplug your Peripheral (if needed), program your Central, and plug your Peripheral back in.
16. Test the following:
 - a. Start Scanning (s)
 - b. Verify that it finds and then connects to your Peripheral
 - c. Disconnect from your Peripheral (d)
17. Create a new global uint16_t variable called ledHandle. HARDCODE its initial value to the handle of your LED Characteristic's Value. You won't change the variable in this exercise, but in a future one you will find the handle via a Service Discovery.
 - a. Hint: Make sure you use the Handle for the Characteristic's Value, not the Characteristic declaration.
18. Create a new function to write the LED Characteristic Value with a uint8_t argument that represents the state of the LED (on CYW920819EVB-02 this is either 0 or 1, while on CYBT-213043-MESH it is a value between 0 and 7). If there is no connection or the ledHandle is 0 then you should just return. Then call the GATT write function.
 - a. Hint: Don't forget to include wiced_memory.h to get access to the get and free buffer functions.
19. In the UART interface call write LED function when values from 0 – 7 are entered.
20. Test Part 3: Unplug your Peripheral (if needed), program your Central, and plug your Peripheral back in.
21. Test the following:
 - a. Start Scanning (s)
 - b. Verify that it finds and then connects to your Peripheral
 - c. Change the LED color by entering values from 0 to 7.
 - d. Disconnect from your Peripheral (d)

Exercise - 4D.4 (Advanced) Add Commands to Turn the CCCD ON/OFF

In this application, you will set up the CCCD to turn on/off Notifications for the button Characteristic and print out messages when Notifications are received.

1. Create a new application called **ch4d_ex04_connect_notify** from the template in templates/ch4d_ex04_connect_notify or import from your previous exercise.
2. After the connection is made using `wiced_bt_gatt_le_connect`, initiate pairing by calling `wiced_bt_dev_sec_bond`. This is necessary because the CCCD permissions for your Peripheral are set such that it cannot be read or written unless the devices are paired first (i.e. Authenticated).
 - a. Hint: Do this in the GATT callback for the connected event, not right after calling `wiced_bt_gatt_le_connect` since you need to wait until the connection is up.
3. Add a new `uint16_t` global variable called `cccdHandle` to hold the handle of the CCCD. Set its initial value to `HDLD_MODUS_COUNTER_CLIENT_CHAR_CONFIG` from your peripheral application (this is hardcoded for now, but we will fix that in the next exercise).
4. Create a new function to write the CDDD for the Button Characteristic with a `uint8_t` argument to turn Notifications off or on. If there is no connection or the `cccdHandle` is 0 then you should return.
 - a. Hint: You can use the function `wiced_bt_util_set_gatt_client_config_descriptor`.
 - b. Hint: add the `gatt_utils_lib` library to your application by adding the necessary lines to the makefile (COMPONENTS and SEARCH_LIBS_AND_INCLUDES) and by adding the header include in the C file.
5. Add cases 'n' and 'N' to set and unset the CCCD using the function you just created.
6. Add a case for `GATT_OPERATION_CPLT_EVT` into the GATT callback. This case should print out the connection id, operation, status, handle, length and the raw bytes of data. This is how you will see the notification values sent back from the peripheral once notifications are enabled.
 - a. Hint: These values are all under the `operation_complete` structure in the event data. Some of them are 2 levels down under `operation_complete.response_data` or 3 levels down under `operation_complete.response_data.att_value`.
 - b. Hint: Use the function `WICED_BT_TRACE_ARRAY` to print out the data array.
7. Unplug your Peripheral (if needed), program your Central, and plug your Peripheral back in.
8. Test the following:
 - a. Start Scanning (s)
 - b. Verify that the connection is made
 - c. Press the button on the peripheral. Notifications are not enabled so you should not see a response.
 - d. Enable Notifications (n)
 - e. Press the button on the peripheral. You should see a response.
 - f. Disable Notifications (N)
 - g. Press the button. You should not see a response.
 - h. Disconnect (d)

Exercise - 4D.5 (Advanced) Make Your Central Do Service Discovery

In this exercise, instead of hardcoding the Handle for the LED and Button CCCD, we will modify our program to do a Service discovery. Instead of triggering the whole process with a state machine, we will use keyboard commands to launch the three stages.

The three stages are:

1. 'q' = Service discovery with the UUID of the Modus Service to get the start and end Handles for the Service Group.
2. 'w' = Characteristic discovery with the range of Handles from step 1 to discover all Characteristic Handles and Characteristic Value Handles.
3. 'e' = Descriptor discovery of the button Characteristic to find the CCCD Handle.

To create the application:

1. Create a new application called **ch4d_ex05_discover** from the template in templates/ch4d_ex05_discover or import from your previous exercise.
2. The gatt_utils_lib has already been added to the makefile.
3. Open the file cycfg_gatt_db.h from the peripheral application and copy over the macros for the following into the app.c file for this exercise:

- a. `__UUID_SERVICE_MODUS`
- b. `__CHARACTERISTIC_MODUS_RGBLED`
- c. `__CHARACTERISTIC_MODUS_COUNTER`
- d. `__UUID_DESCRIPTOR_CLIENT_CHARACTERISTIC_CONFIGURATION`

Hint: This guarantees that the Central uses the same UUIDs that are used in the Peripheral.

4. Create variables to save the start and end Handle of the Modus Service and create a variable to hold the Modus Service UUID (if you don't already have one).

```
static const uint8_t modusServiceUUID[] = { __UUID_SERVICE_MODUS };
static uint16_t serviceStartHandle = 0x0001;
static uint16_t serviceEndHandle = 0xFFFF;
```

5. Make a new structure to manage the discovered handles of the Characteristics:

```
typedef struct {
    uint16_t startHandle;
    uint16_t endHandle;
    uint16_t valHandle;
    uint16_t cccdHandle;
} charHandle_t;
```

6. Create a charHandle_t for the LED and the Counter as well as the Characteristic UUIDs to search for.

```
static const uint8_t ledUUID[] = { __CHARACTERISTIC_MODUS_LED };
static charHandle_t ledChar;

static const uint8_t counterUUID[] = { __CHARACTERISTIC_MODUS_COUNTER };
```

```
static charHandle_t counterChar;
```

7. Create an array of charHandle_t to temporarily hold the Characteristic Handles. When you discover the Characteristics, you won't know what order they will occur in, so you need to save the Handles temporarily to calculate the end of group Handles.

```
#define MAX_CHARS_DISCOVERED (10)
static charHandle_t charHandles[MAX_CHARS_DISCOVERED];
static uint32_t charHandleCount;
```

Service Discovery

8. Add a function to launch the Service discovery called "startServiceDiscovery". This function will be called when the user presses 'q'. Instead of finding all the UUIDs you will turn on the filter for just the Modus Service UUID.
 - a. Setup the wiced_bt_gatt_discovery_param_t with the starting and ending Handles set to 0x0001 & 0xFFFF.
 - b. Setup the UUID to be the UUID of the Modus Service.
 - c. Use memcpy to copy the Service UUID into the wiced_bt_gatt_discovery_param_t.
 - d. Set the discovery type to GATT_DISCOVER_SERVICES_BY_UUID and launch the wiced_bt_gatt_send_discover.
9. Add the case GATT_DISCOVERY_RESULT_EVT to your GATT Event Handler. If the discovery type is GATT_DISCOVER_SERVICES_BY_UUID then update the serviceStart and serviceEnd Handle with the actual start and end Handles (remember GATT_DISCOVERY_RESULT_SERVICE_START_HANDLE and GATT_DISCOVERY_RESULT_SERVICE_END_HANDLE).

Characteristic Discovery

10. Add a function to launch the Characteristic discovery called "startCharacteristicDiscovery" when the user presses 'w'.
 - a. Setup the wiced_bt_gatt_discovery_param_t start and end Handle to be the range you discovered in the previous step.
 - b. Call wiced_bt_gatt_send_discover with the discovery type set to GATT_DISCOVER_CHARACTERISTICS.
11. In the GATT_DISCOVERY_RESULT_EVT of your GATT Event Handler add an "if" for the Characteristic result. In the "if" you need to save the startHandle and valueHandle in your charHandles array. Set the endHandle to the end of the Service Group (assume that this Characteristic is the last one in the Service). If this is not the first Characteristic, then set the previous Characteristic end handle:

```
if( charHandleCount != 0 )
{
    charHandles[charHandleCount-1].endHandle = charHandles[charHandleCount].endHandle-1;
}
charHandleCount += 1;
```

The point is to assume that the Characteristic ends at the end of the Service Group. But, if you find another Characteristic, then you know that the end of the previous Characteristic is the start of the new one minus 1.

Then you want to see if the Characteristic is the Counter or LED Characteristic. If it is one of those, then also save the start, end and value Handles.

Descriptor Discovery

12. Add a function to launch the Descriptor discovery called “startDescriptorDiscovery” when the user presses ‘e’. The purpose of this function is to find the CCCD Handle for the counter Characteristic.
 - a. It will need to search for all the Descriptors in the Characteristic Group.
 - b. The start will be the Counter Value Handle + 1 to the end of the group handle.
 - c. Once the parameters are setup, launch `wiced_bt_gatt_send_discover` with `GATT_DISCOVER_CHARACTERISTIC_DESCRIPTOR`.
13. In the `GATT_DISCOVERY_RESULT_EVT` of your GATT Event Handler add an “if” for the Descriptor result. If the Descriptor UUID is `_UUID_DESCRIPTOR_CLIENT_CHARACTERISTIC_CONFIGURATION` then save the Button CCCD Handle.
14. The last change you need to make in the GATT callback is for the `GATT_DISCOVERY_CPLT_EVT`. You should check to see if it is a Characteristic discovery. If it is, then you will be able figure out the endHandle for each of the LED and Button Characteristic by copying them from the `charHandles` array. Your code could look something like this:

```
// Once all characteristics are discovered... you need to setup the end handles
if( p_event_data->discovery_complete.disc_type == GATT_DISCOVER_CHARACTERISTICS )
{
    for( int i=0; i<charHandleCount; i++ )
    {
        if( charHandles[i].startHandle == ledChar.startHandle )
            ledChar.endHandle = charHandles[i].endHandle;

        if( charHandles[i].startHandle == counterChar.startHandle )
            counterChar.endHandle = charHandles[i].endHandle;
    }
}
```

15. Add the function calls for ‘q’, ‘w’, and ‘e’. Also add those keys to the help print out.
16. Unplug your Peripheral (if needed), program your Central, and plug your Peripheral back in.
17. Test the following:
 - a. Start Scanning (s)
 - b. Discover the Modus Service (q)
 - c. Discover the Counter and LED Characteristics (w)
 - d. Discover the Button CCCD (e)
 - e. Turn on the LED (1...7)
 - f. Turn off the LED (0)
 - g. Turn on notification (n)
 - h. Press the button on the Peripheral and make sure it works
 - i. Turn off notification (N)
 - j. Press the button on the Peripheral to make sure the notification is off

Exercise - 4D.6 (Advanced) Run the Advertising Scanner

In this exercise you will experiment with a full-function advertising scanner application.

1. Create a new application called **ch4d_ex06_AdvScanner** from the template in templates/ch4d_ex06_AdvScanner.
2. Open a UART terminal window.
3. Unplug your Peripheral (if needed), program your Central, and plug your Peripheral back in.
4. Once the application starts running press "?" to get a list of available commands.
5. Use 's' and 'S' to enable/disable scanning
6. Use 't' to print a single line table of all devices that have been found
 - a. This table will show raw advertising data
7. Use 'm' to print a multi-line table of all devices
 - a. This table will show both raw advertising data and decoded data
 - b. Use '?' to get a list of table commands
 - c. Use '<' and '>' to change pages
 - d. Use 'ESC' to exit the table
8. To filter on a specific device, enter its number from the table
9. Use 'r' to list recent packets from the filtered device
 - a. Use '?' to get a list of table commands
 - b. Use '<' and '>' to change pages
 - c. Use 'ESC' to exit the table