IoT Engineering
5: Local Connectivity with Bluetooth LE

Today

⅓ slides,

⅔ hands-on.

Slides, code & hands-on: tmb.gr/iot-5

Prerequisites

Install the Arduino IDE and set up the nRF52840:

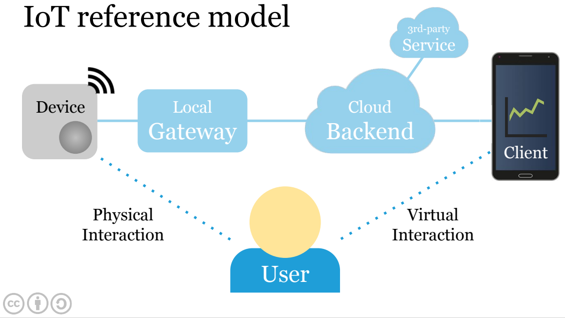
Check the Wiki entry on Installing the Arduino IDE.

Set up the Feather nRF52840 Express for Arduino.

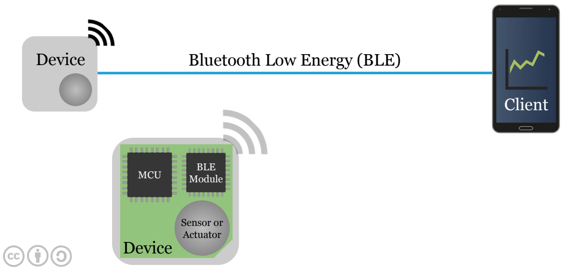
Setting up the board also installs this BLE library.

For testing a smartphone with BLE is required.

IoT reference model



BLE connectivity



App + accessory

Local sensing/control, local connectivity.

Sensor → Device → Client app

E.g. blood sugar measurements.

Actuator ← Device ← Client app

E.g. insulin pump control data.

A → B: measurement or control data flow.

Bluetooth Low Energy (BLE)

BLE is a power-efficient Bluetooth variant (since 4.0).

BLE is well suited for small, battery powered devices.

BLE uses less energy than Wi-Fi, way less than 3/4G.

Both, classic Bluetooth and BLE, use 2.4 GHz radio.

The standard is maintained by the Bluetooth SIG.

How BLE works

Peripherals advertise the data they have, over the air.

Centrals scan for nearby peripherals to discover them.

The central connects to a peripheral and uses its data.

Data is transmitted through *services* & *characteristics*.

BLE protocol stack

Application — e.g. on smartphone or microcontroller
BLE library — thin, language-specific wrapper library

GATT — services & characteristics | GAP — discovery
ATT — attribute transport | SMP — security manager
L2CAP — logical link control and adaptation protocol

Link layer — exposed via the host controller interface
Physical layer — dealing with actual radio signals

Generic Access Profile (GAP)

GAP defines the following roles, communication types:

Broadcaster and *observer* (connectionless, one-way).

Peripheral and *central* (bidirectional connection).

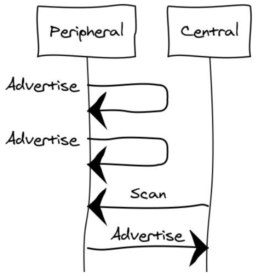
Each device supports one or more of these roles.

We start with peripheral and central roles.

Advertising

A peripheral *advertises* its services by broadcast, in a regular interval.

A central *scans* for all or a subset of services and gets device addresses and, if it's been sent, advertised data.



Attribute Transport (ATT)

ATT allows a *client* to access attributes on a *server*.

An *attribute* has a UUID, a handle and permissions.

A *UUID* is a 32/128-bit universally unique identifier.

An *attribute handle* is a server-assigned, 16-bit ID.

See Bluetooth spec v5.1, Part F, p. 2288.

Generic Attribute Profile (GATT)

GATT is a simple application level protocol for BLE.

It's connection-based, with a *client* and a *server* role.

This enables a BLE device to provide a RESTful API.

A "GATT API", or *profile*, is a collection of *services*.

Usually, the peripheral acts as a server.

Services

A GATT service is a collection of characteristics.

Services encapsulate the behavior of part of a device.

In addition, such a service can refer to other services.

There are standard and custom services and profiles.

E.g. the Battery Service or the Heart Rate Service.

Characteristics

A GATT characteristic has a value and descriptors.

A *value* encodes data "bits" that form a logical unit.

Descriptors are defined attributes of a characteristic.

Supported procedures: read, write and notifications.

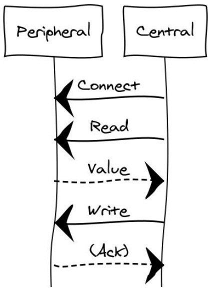
E.g. a Battery Level or a Heart Rate Measurement.

Read and write

Connect = the central connects to a peripherals BLE address.

Read = value of a characteristic or its descriptors is returned.

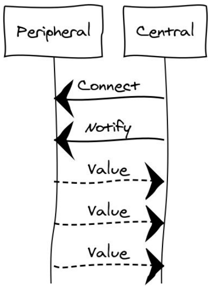
Write = characteristic value, or characteristic descriptor value is set, with/without response.



Notifications

Notify = *Client Characteristic Configuration* descriptor of a characteristic, UUID `0x2902`, is set to `0x0000` using *Write*.

Value = A *Handle Value Notification* is sent if value changes.



See Bluetooth spec v5.1, p. 2360 and p. 2389.

BLE explorer apps

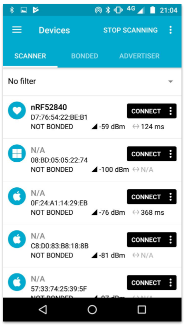
For debugging, use any generic BLE explorer app:

Find BLE explorer apps on the Google Play Store.

Search for "BLE explorer" in the iOS App Store.

Smartphones can act as central or peripheral.

Exploring is a great way to learn about BLE.



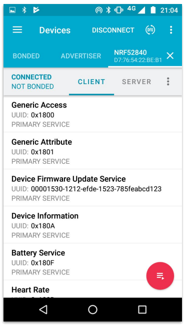
nRF52840
D7:76:54:22:BE:B1
NOT BONDED -59 dBm ↔ 124 ms
CONNECT

N/A
08:BD:05:05:22:74
NOT BONDED -100 dBm ↔ N/A
CONNECT

N/A
0F:24:A1:14:29:EB
NOT BONDED -76 dBm ↔ 368 ms
CONNECT

N/A
C8:D0:83:B8:18:8B
NOT BONDED -81 dBm ↔ N/A
CONNECT

N/A
57:33:74:25:39:5F
CONNECT



Generic Access
UUID: 0x1800
PRIMARY SERVICE

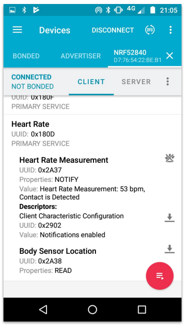
Generic Attribute
UUID: 0x1801
PRIMARY SERVICE

Device Firmware Update Service
UUID: 00001530-1212-efde-1523-785feabcd123
PRIMARY SERVICE

Device Information
UUID: 0x180A
PRIMARY SERVICE

Battery Service
UUID: 0x180F
PRIMARY SERVICE

Heart Rate



UUID: 0x180F
PRIMARY SERVICE

Heart Rate
UUID: 0x180D
PRIMARY SERVICE

Heart Rate Measurement
UUID: 0x2A37
Properties: NOTIFY
Value: Heart Rate Measurement: 53 bpm, Contact is Detected
Descriptors:
Client Characteristic Configuration
UUID: 0x2902
Value: Notifications enabled

Body Sensor Location
UUID: 0x2A38
Properties: READ

Heart Rate Service

This service is intended for fitness heart rate sensors:
`Heart Rate Service UUID (16-bit): 0x180D`

This service includes the following characteristics:

`Heart Rate Measurement`	`UUID: 0x2A37`	`[N]`
`Body Sensor Location`	`UUID: 0x2A38`	`[R]`
`Heart Rate Control Point`	`UUID: 0x2A39`	`[W]*`

*) Optional, see Heart Rate Service specification.

nRF52840 HRM BLE Peripheral .ino

```
hrmSvc = BLEService(0x180D); // See HRM spec
hrmChr = BLECharacteristic(0x2A37); // See spec

hrmSvc.begin(); // to add characteristics
hrmChr.setProperties(CHR_PROPS_NOTIFY); …
hrmChr.begin(); // adds characteristic

uint8_t hrmData[2] = { 0b00000110, value };
hrmChr.notify(hrmData, sizeof(hrmData));
```

Hands-on, 10': HRM BLE Peripheral

Build and run the previous nRF52840 BLE example.

Use the *.ino* link on the page to find the source code.

Explore the HRM example using a smartphone app.

Draw the HRM profile as a tree, with services, etc.

Nordic UART Service

This service provides a serial connection over BLE:
`Nordic UART Service custom (128-bit) UUID:`
`6E400001-B5A3-F393-E0A9-E50E24DCCA9E`

This service includes the following characteristics:

`RX (device receives data)`	`UUID: 0x0002`	`[W]`
`TX (device transmits data)`	`UUID: 0x0003`	`[N]`

This service is becoming a de facto standard.

nRF52840 UART BLE Peripheral .ino

```
// UUID: 6E400001-B5A3-F393-E0A9-E50E24DCCA9E
uint8_t const uartSvcUuid[] = { 0x9E, 0xCA, …,
0xB5, 0x01, 0x00, 0x40, 0x6E }; // lsb first

uartSvc = BLEService(uartSvcUuid); // 128-bit
rxChr = BLECharacteristic(rxChrUuid); // 128-b.
txChr = BLECharacteristic(txChrUuid); // 128-b.

txChar.setProperties(CHR_PROPS_NOTIFY);
rxChar.setProperties(CHR_PROPS_WRITE);
```

Hands-on, 10': UART BLE Peripheral

Build and run the previous nRF52840 BLE example.

Use the *.ino* link on the page to find the source code.

Send data to the device using the nRF Connect app.

Done? Compare the above to Adafruit's bleuart.ino.

nRF52840 UART BLE Central .ino

```
Bluefruit.begin(0, 1); // 1 central connection
uartSvcClient.begin();
uartSvcClient.setRxCallback(rxCbck); // read
Bluefruit.Central.setConnectCallback(connCbck);

void connCbck(uint16_t connHandle) {
  if (uartSvcClient.discover(connHandle)) {
    uartSvcClient.enableTXD(); // enable notify
    uartServiceClient.print(…); // write data
    …
```

nRF52840 UART BLE Central (ff.) .ino

```
Bluefruit.Scanner.setRxCallback(found);

void found(ble_gap_evt_adv_report_t* report) {
  if (….Scanner.checkReportForService(
    report, uartServiceClient)) {
    Bluefruit.Central.connect(report);
  } else {
    Bluefruit.Scanner.resume();
  }
}
```

Hands-on, 10': UART BLE Central

Build and run the previous nRF52840 BLE example.

Use the *.ino* link on the page to find the source code.

Send data to a nRF52840 UART peripheral device.

Make sure every sent byte arrives at the other side.

Beacons

Beacons, e.g. Apple iBeacon are *broadcaster* devices.

Any *observer* can read the data from they advertise.

Lookup of "what a beacon means" requires an app.

Except for Physical Web / Eddystone beacons.

These contain an URL to be used right away.

nRF52840 Beacon BLE Observable .ino

```
BLEBeacon beacon(
  beaconUuid, // AirLocate UUID
  beaconMajorVersion,
  beaconMinorVersion,
  rssiAtOneMeter);
beacon.setManufacturer(0x004C); // Apple
startAdvertising();

suspendLoop(); // save power
```

Hands-on, 10': Beacons

Build and run the previous nRF52840 BLE example.

Use the *.ino* link on the page to find the source code.

Test the beacon with a dedicated iOS/Android app.

Which information is transferred by a beacon?

If you happen to be at Zürich HB, start a scan...

nRF52840 Scanner BLE Central .ino

```
Bluefruit.begin(0, 1); // Central
Bluefruit.Scanner.setRxCallback(found);
Bluefruit.Scanner.start(0);

void found(ble_gap_evt_adv_report_t* report) {
  Serial.printBufferReverse( // little endian
    report->peer_addr.addr, 6, ':');
  if (Bluefruit.Scanner.checkReportForUuid(…))…
  Bluefruit.Scanner.resume();
}
```

Hands-on, 10': Scanner BLE Central

Build and run the previous nRF52840 BLE example.

Use the *.ino* link on the page to find the source code.

Add a *checkReportForUuid()* for the Battery Service.

Can you spot the UUID in the advertising data?

Consider working in teams => more nRF52840.

Security

BLE has security mechanisms for pairing and more.

Pairing: exchanging identity and keys to set up trust.

Device chooses *Just Works*, *Passkey Entry* or OOB.

Or numeric comparison and ECDH for key exchange.

Some apps add encryption* on the application layer.

*) See, e.g. HomeKit in iOS Security Guide (p. 29).

Hands-on, 10': HomeKit

HomeKit is a proprietary home-automation system.

Try *File* > *Examples* > *Adafruit Bluefruit nRF52* > *Projects* > *HomeKit* > *homekit_lightbulb*

An iOS device is required to test the peripheral.

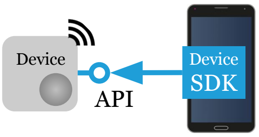
Read the code, how is security implemented?

Device API vs. SDK

A *device API* specifies how to talk to the device, from any client (here via BLE).

A platform specific *device SDK* simplifies integration.

E.g. *iOS device SDK* to talk to a device API from iOS.



```
Battery Service
  Battery Level [R]
vs.
p = ble.conn(addr);
b = sdk.getBatt(p);
x = b.getLevel();
```

BLE on Android

There is an official introduction to BLE on Android.

Building a robust BLE app on Android can be tricky.

Use the Nordic Semiconductor Android-BLE-Library.

As an example app, look at the nRF Toolbox project.

Writing a plugin for nRF Toolbox is quite easy.

BLE on iOS

On iOS the official BLE library is Core Bluetooth.

Its documentation is a great introduction to BLE.

In iOS there's no way to get a device BLE address.

Instead, a UUID is assigned, as a handle, by iOS.

iOS devices change their Bluetooth MAC address.

BLE on Raspberry Pi

On Raspberry Pi Zero W there are many options, e.g.

Node.js libraries: Noble (central), Bleno (peripheral)

Python library: PyBluez, BluePy

Linux C library: Bluez

CLI: bluetoothctl

Summary

We looked at BLE, Bluetooth for constrained devices.

We saw how centrals scan for advertising peripherals.

We used services to read/write characteristic values.

We met a custom Bluetooth profile for UART serial.

Next: Raspberry Pi as a Local Gateway.

Homework, max. 3h

Set up the Raspberry Pi Zero W via USB and Wi-Fi.

See Raspberry Pi Zero W Setup in the Wiki.

Make sure you've got SSH access.

Submit the MAC address.

Setup via USB can take a few tries, keep trying :)

Feedback?

Find me on https://fhnw-iot.slack.com/

Or email thomas.amberg@fhnw.ch

Slides, code & hands-on: tmb.gr/iot-5