



Bluetooth Low-Energy 5.0 Throughput Testing

Louis Wang | Senior Software Engineer



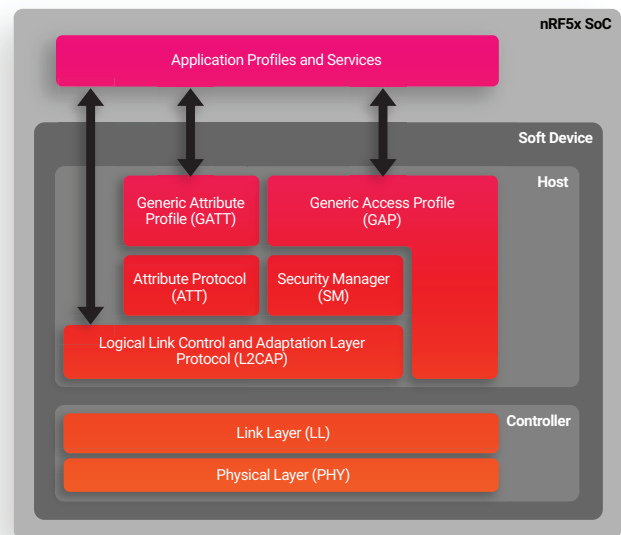
Abstract — Bluetooth is a wireless technology used in many applications. There are many versions improving every year meeting the needs of users. The newest version improved to bring more support than previous versions. Bluetooth 5.0 is a further development of Bluetooth low-energy technology, which greatly increases the performance of the previous versions. The improvements mainly relate to the high speed LE 2M physical layer data rate and LE long-range transmission. This document will focus on throughput testing, and analyzes the different parameters settings will cause different throughput results.

I - Introduction

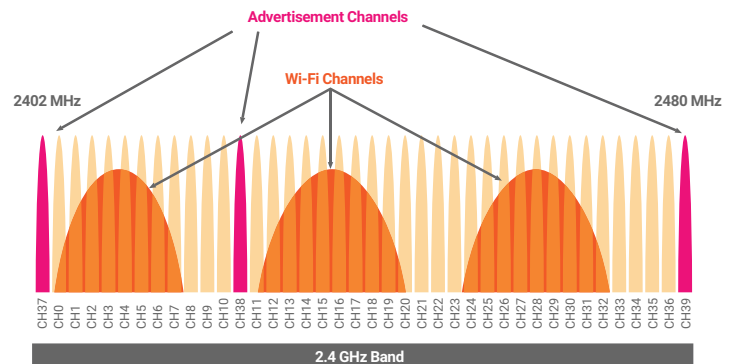
We use 2 Nordic nRF52840-DK boards to do throughput testing. One of the boards acts as a central (master) and another acts as a peripheral (slave). At the first, we give an overview of BLE connection procedure. Second, we talk about the GATT (Generic Attribute Profile) protocol factors, ATT_MTU, Data Length Extension and connection interval. Finally, based on these experiments, we show how to optimize for maximum data throughput in BLE 5.

II - BLE Stack and Frequency Channels

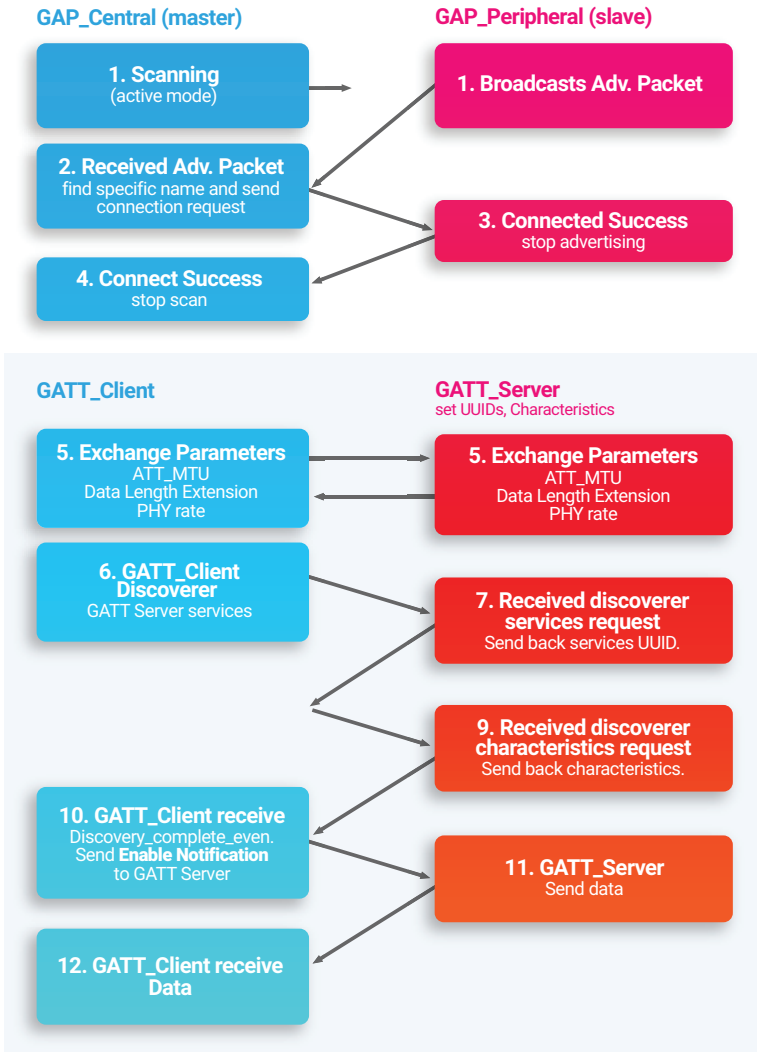
SoftDevice S140 is a feature complete Bluetooth 5 qualified protocol stack for the nRF52840 SoC. The S140 SoftDevice is a Bluetooth Low Energy Central and Peripheral protocol stack solution. The S140 SoftDevice integrates a Bluetooth Low Energy controller and host and provides a flexible API for building Bluetooth Low Energy nRF52X SoC solutions. The development and experiment is based on nRF5_SDK V15.3.0.



BLE uses channels 0-36 for data transmission (light orange in picture below) while channel 37, 38 and 39 are used as advertising channels (pink in picture below).



III - BLE Connection Procedure



If central finds the peripheral with specific name it will send a connection request to the peripheral. After connected, GATT client and server will exchange parameters including ATT_MTU, Data Length Extension and PHY rate.

IV - GATT Parameters Setting

ATT_MTU size:

The Attribute Maximum Transmission Unit (ATT_MTU) defines the amount of data a device can send/receive per GATT operation. The default MTU is 23 bytes and can be increased to 247 bytes. When increasing this value longer payloads can be achieved by sending several packets for one transaction. In order to fully utilize the use of Data Length Extension, the MTU should always be set to (Maximum Data Length - 4). This means that for the maximum data length of 251, the optimum MTU to set is 247 bytes.

Data Length Extension (DLE):

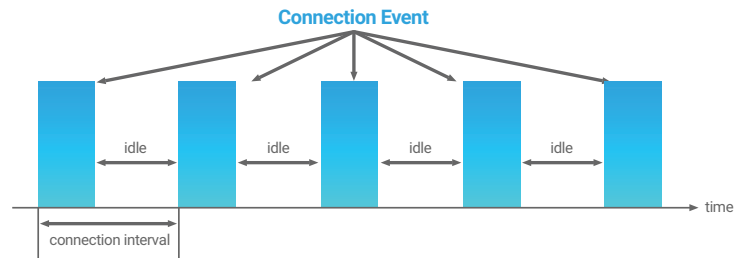
The data length extension feature allows the LE controller to send packet data units (PDUs) with payloads of up to 251 bytes. Data length extension allows using larger packets, so that more data can be sent in one packet, increasing throughput. The nRF52840 supports the increase of the data packet length from the default 27 to the maximum value allowed by the Bluetooth spec which is 251 bytes.

Physical layer (PHY) data rate:

The over-the-air data rate used to be limited to 1Mbps in BLE. Starting with Bluetooth 5, higher data rates are permitted to achieve faster transmission and it is possible to use coded PHY for long-range transmissions.

Connection interval:

A BLE connection interval is the time between two data transfer events (connection events) between the central and the peripheral device. When increasing this value, more packets may be sent in one interval but if a packet is lost, the wait until the re-transmission is longer. Increasing this value can increase throughput, provided that the GAP event length increases by the same amount or connection event length extension is enabled.



V - Throughput Test

Test case-1: Different PHY rate

PHY rate	MTU	Data Length	DLE	Connection Interval	Throughput
2 Mbps	247 Bytes	251 Bytes	ON	400 ms	1,317 Kbps
1 Mbps	247 Bytes	251 Bytes	ON	400 ms	760 Kbps
15 Kbps	247 Bytes	251 Bytes	ON	400 ms	57 Kbps

Increasing PHY rate results in throughput improvement.

Test case-2: Different ATT_MTU

PHY rate	MTU	Data Length	DLE	Connection Interval	Throughput
2 Mbps	247 Bytes	251 Bytes	ON	400 ms	1,315 Kbps
2 Mbps	158 Bytes	251 Bytes	ON	400 ms	1,072 Kbps
2 Mbps	27 Bytes	251 Bytes	ON	400 ms	359 Kbps

Increasing ATT_MTU results in throughput improvement.

Test case-3: DLE enable/disable

PHY rate	MTU	Data Length	DLE	Connection Interval	Throughput
2 Mbps	247 Bytes	251 Bytes	ON	400 ms	1,317 Kbps
2 Mbps	247 Bytes	251 Bytes	ON	400 ms	1,069 Kbps

Enable Data Length Extension (DLE) will increase throughput.

Test case-4: Different connection interval

PHY rate	MTU	Data Length	DLE	Connection Interval	Throughput
2 Mbps	247 Bytes	251 Bytes	ON	400 ms	1,316 Kbps
2 Mbps	247 Bytes	251 Bytes	ON	50 ms	1,309 Kbps
2 Mbps	247 Bytes	251 Bytes	ON	7.5 ms	1,047 Kbps

Increasing connection interval result in throughput improvement.

Test case-5: Different connection interval—one device (client) is shaded partially to simulate the packets lost.

PHY rate	MTU	Data Length	DLE	Connection Interval	Throughput
2 Mbps	247 Bytes	251 Bytes	ON	400 ms	102 Kbps
2 Mbps	247 Bytes	251 Bytes	ON	50 ms	160 Kbps
2 Mbps	247 Bytes	251 Bytes	ON	7.5 ms	367 Kbps

This test case aims to simulate when packet loss happens, the wait until the re-transmission is longer. This reason will cause slower throughput. When the value of connection interval is longer, the throughput is worse. The level to set the connection interval depends on the packet loss and the environmental effect.

Optimizing for maximum data throughput

- Always enable DLE
 - If you're using Bluetooth v4.1 or earlier, this is not a valid option.
- Use LE 2M PHY
 - If you know that the devices on both ends support BLE 5, choosing the LE 2M PHY is one of the best ways to maximize your application data throughput.
- Use maximum ATT MTU value 247 bytes.
- Connection interval parameter depends on the testing environment. Chose maximum interval time if there is no packet loss.