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Practical BLE Throughput

Overview

The original Bluetooth specification was intended to be a replacement of the common RS232 serial port that was prevalent at that time. Over the years, Bluetooth communications have evolved to now include several types of connections, each with its own target data types and speeds.

In 2016, the Bluetooth SIG adopted the following identifiers to clarify the different types of communications:

- **Bluetooth wireless technology**: This is the overall identifier for all types of Bluetooth connections.
- **Bluetooth high speed technology**: Most connections that require streaming data, at a significant and sustained rate: 1Mbps (BR), 3Mbps (EDR) and as high as 24Mbps (HS).
- **Bluetooth low energy technology**: These connections were introduced in version 4.0 of the Bluetooth Specification and are targeted for low data rate and/or low power applications.
  Data is sent at intervals that can vary from 7.5ms to as long as 4 seconds.

This document focuses on Bluetooth low energy technology, providing sample calculations for expected throughput.

Bluetooth low energy technology

The maximum achievable data rate depends heavily on a few different factors. The primary factor is the selection of a connection interval which is part of the BLE connection parameters. The next major factor is the operating system. Connection parameters, the operating system and power considerations are discussed here. Other minor factors that are less controllable may also need considered, such as interference.

Connection Parameters

As part of BLE, the peripheral device maintains a set of connection parameters that contain the following:

- Minimum Connection Interval (Min CI)
  - This is the minimum amount of time that may pass before the central connects to check for new data or write new data
  - Specified in 1.25ms increments, Range: 6 to 3200; Less than or equal to Max CI
- Maximum Connection Interval (Max CI)
  - This is the maximum amount of time that may pass before the central connects to check for new data or write new data
  - Specified in 1.25ms increments, Range: 6 to 3200, Greater than or equal to Min CI

- Slave Latency
  - This parameter specifies the number of connection events a peripheral may ignore if it has nothing to report
  - The Slave Latency field shall have a value in the range of 0 to $Slave\ latency = \frac{Supervisory\ Timeout}{(Max\ CI*2)} - 1;\ Slave\ latency < 500$
- Timeout Multiplier (defines Supervisory Timeout)
  - If a peripheral is not heard from for Timeout amount of time, then it is considered out of range or disconnected
  - Range: 10 to 3200
  - $Supervisory\ Timeout = Timeout\ Multiplier * 10ms$

The average connection interval is as follows:

$$Avg\ CI = \frac{Min\ CI + Max\ CI}{2}$$

The Min CI and Max CI are allowed to be equal, though they frequently are not. Slave Latency is a more advanced use of the connection parameters and is not relevant to this current discussion.

Once the connection parameters are selected, then the maximum data rate depends on a simple equation which also incorporates the Maximum Transmission Unit or MTU. The BMD-200 (nRF51) has a MTU of 20 bytes, using SoftDevice S130. The BMD-300 Series (nRF52) currently also has a MTU of 20 bytes, using SoftDevice S132.

Therefore, the maximum throughput in bits per second, based only on connection parameters, is:

$$Max\ Throughput\ (bps) = \left(\frac{1}{Avg\ CI}\right) * \left(\frac{1000ms}{sec}\right) * MTU(in\ bytes) * \left(\frac{8bits}{byte}\right)$$

If both the Max CI and Min CI are set to the minimum allowed connection interval of 7.5ms, and with a MTU at 20 bytes, the theoretical maximum throughput becomes:

$$Max\ Throughput\ (bps) = \left(\frac{1}{7.5ms}\right) * \left(\frac{1000ms}{sec}\right) * 20bytes * \left(\frac{8bits}{byte}\right) = 21300\ bps = 21.3\ kbps$$

Note: *The nRF52 itself supports Bluetooth Low Energy packet length extension. Future versions of S132 are expected to take advantage of this feature, and consequently increase the maximum throughput.*

Note: *Higher data rates are possible when communicating between two nRF based devices. See the following Nordic DevZone post regarding 6 packets per connection interval: https://devzone.nordicsemi.com/question/62269/s132-v2-how-to-pass-6-packets-per-connection-interval/*

Operating System Considerations

The next item to consider is the operating system to which the peripheral is connected. For a situation where both ends of the RF connection are controlled, for example one BMD-300 as the central and another as the peripheral, the minimum allowable interval of 7.5ms can be specified and the maximum rate of 21.3Kbps approached.

However, when connecting to iOS, the minimum possible interval is 20ms for most devices. iOS may make exceptions for HID devices and negotiate an interval down to 11.25ms. This information is available in the Apple Bluetooth Design Guidelines, section 3.6. These timing changes reduce the maximum possible throughput for iOS:

$$Avg\ CI\ iOS = \left(\frac{20\ ms + Max\ CI}{2}\right)$$

$$Max\ Throughput\ for\ iOS = \left(\frac{1}{Avg\ CI\ iOS}\right) * \left(\frac{1000ms}{sec}\right) * 20bytes * \left(\frac{8bits}{byte}\right) = 8\ kbps$$

$$Max\ Throughput\ for\ iOS\ over\ HID = \left(\frac{1}{11.25ms}\right) * \left(\frac{1000ms}{sec}\right) * 20bytes * \left(\frac{8bits}{byte}\right) = 14.2\ kbps$$

There are additional limitations on connection parameters iOS will accept. See Apple Bluetooth Design Guidelines for more information. On Android and Windows Mobile, there are no documents similar to Apple's Bluetooth guidelines. Similar limitations likely exist in order to balance battery use in conjunction with Bluetooth use.

Power Considerations

BLE is called Low Energy for a reason. The goal for most BLE implementations is to send small amounts of data infrequently. The actual signaling rate of BLE, 1Mbps, allows the system to turn on the radio, quickly send and receive data, then turn off the radio to save as much power as possible.

With that in mind, the power required to achieve maximum throughput is much higher when compared to sending a small amount of data every second or so. If the target design is battery powered, then it is critical to examine the tradeoff between power consumption and data throughput.

Actual use

The currently available average throughput is approximately 8kbps through common mobile operating systems, regardless of the module being used. While the BMD-300 uses the nRF52 which will ultimately support larger packets, the actual usable size depends on the OS.

Related Documents

Rigado Documents:

- BMD-200-DS: Module Datasheet
- BMD-300-Series-DS: Module Datasheet
- BMD-200-AN-1: MAC Address Provisioning

Nordic Semiconductor Documents (available at the Nordic Semiconductor Infocenter)**:**

- nRF51822-PS: nRF51822 Product Specification
- nRF52832-PS: nRF52832 Product Specification
- nRF51 RM: nRF51 Series Reference Manual
- S110-SDS: nRF51822 S110 SoftDevice Specification
- S130-SDS: nRF51822 S130 SoftDevice Specification
- S132-SDS: nRF52832 S132 SoftDevice Specification

Document History

Revision	Date	Author	Changes / Notes
1.0	04/07/2016	BR / ES	Initial Release
1.0.1	05/06/2016	BR	Updated logo
1.0.2	05/19/2016	BR	Changed filename