ANR006 HIGH THROUGHPUT MODE

PROTEUS-II AND PROTEUS-III

VERSION 1.3

FEBRUARY 19, 2020
## Revision history

<table>
<thead>
<tr>
<th>Manual version</th>
<th>Notes</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>• Initial version</td>
<td>November 2018</td>
</tr>
<tr>
<td>1.1</td>
<td>• Updated file name to new AppNote name structure. Updated important notes, legal notice &amp; license terms chapters.</td>
<td>June 2019</td>
</tr>
<tr>
<td>1.2</td>
<td>• Updated address of Division Wireless Connectivity &amp; Sensors location</td>
<td>October 2019</td>
</tr>
<tr>
<td>1.3</td>
<td>• Added new test results of Proteus-II and Proteus-III</td>
<td>February 2020</td>
</tr>
</tbody>
</table>
## Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Payload</td>
<td></td>
<td>The intended message in a frame / package.</td>
</tr>
<tr>
<td>RF</td>
<td>Radio frequency</td>
<td>Describes wireless transmission.</td>
</tr>
<tr>
<td>UART</td>
<td>Universal Asynchronous Receiver Transmitter</td>
<td>Allows the serial communication with the module.</td>
</tr>
<tr>
<td>[HEX] 0xhh</td>
<td>Hexadecimal</td>
<td>All numbers beginning with 0x are hexadecimal numbers. All other numbers are decimal, unless stated otherwise.</td>
</tr>
</tbody>
</table>
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1 Introduction

The Proteus series is a product series of Bluetooth® modules based on the nRF52 Nordic Semiconductors SoC which presents various Bluetooth® LE and low power features. Bluetooth® LE enabled devices allow to transmit/receive data in a short interval after the connection event. During this period, by default one data packet of up to 251 Bytes is transmitted from master to slave and one data packet from slave to master. After the transmission, the device goes to sleep until the next connection event occurs (see figure 1).

Due to this procedure, the device is suited for low power applications, but it’s default radio throughput is limited\(^1\) to:

\[
\frac{\text{Data per packet}}{\text{Connection interval}} [\text{Byte/s}] \quad (1)
\]

To overcome this limitation, for Proteus-II and Proteus-III a new mode has been introduced. This so called "high throughput mode" enables to transmit/receive up to 4 Bluetooth® LE packets per connection interval (see figure 2). With this the throughput of a Bluetooth® LE connection can be increased, at the expense of a higher energy consumption.

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\(^1\)Please note that there are further conditions that slow down the throughput, like the UART speed and the \(\mu\)C processor speed.
1.1 Compatibility and risks

By default Bluetooth® LE enabled devices support the transmission of one data packet in a short period after the connection event. With upcoming new Bluetooth® LE devices an increasing number of data packets per connection interval is supported. Modern iOS devices support up to 4 packets, Android devices support up to 6 packets per connection interval:

<table>
<thead>
<tr>
<th>Device</th>
<th>Number of packets per connection interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Samsung Galaxy S8</td>
<td>4</td>
</tr>
<tr>
<td>Nexus 4, Nexus 6P</td>
<td>6</td>
</tr>
<tr>
<td>OnePlus 5</td>
<td>6</td>
</tr>
<tr>
<td>iPhone 6, 7, Xs</td>
<td>4</td>
</tr>
</tbody>
</table>

Table 1: Examples of Bluetooth® LE enabled devices supporting this feature

As only one packet per connection interval must be supported by a Bluetooth® LE connection, there is always a risk that the connection partner does not support this feature.
2 Usage

To enable the high throughput mode the corresponding bit in the CfgFlags has to be set by using the CMD_SET_REQ command.

2.1 Maximum packet size

During the connection setup the module outputs a CMD_CHANNELOPEN_RSP message on the UART. This message contains the maximum payload of a standard packet ($\Phi_{ST}$). Keeping this value in mind, the maximum packet to be transmitted via the CMD_DATA_REQ in high throughput mode is calculated as:

\[
\Phi_{HTM} = (\Phi_{ST} - 3 + 1) \times 4[\text{Bytes}]
\]

In case of the largest maximum transmission unit (MTU), that is supported by the Proteus modules, the size of the standard packet $\Phi_{ST}$ is 243 (0xF3) Bytes. Therefore, the largest packet size $\Phi_{HTM}$ in high throughput mode calculates as 964 Bytes.

2.2 Bluetooth LE packet format

The standard Bluetooth® LE packet of a Proteus module has the following format:

<table>
<thead>
<tr>
<th>Bluetooth® LE packet</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMBER header</td>
</tr>
<tr>
<td>Payload</td>
</tr>
<tr>
<td>1 Byte</td>
</tr>
<tr>
<td>$\Phi_{ST}$ Bytes</td>
</tr>
</tbody>
</table>

Table 2: Bluetooth® LE packet format of a standard packet

where:

**AMBER header** is 0x01 (RF_HEADER_TYPE_DATA), meaning that the following Bytes are payload.

To send bigger data packets, the data is fragmented to up to 4 single packets. These fragmented data packets contain an extended header of 3 Bytes length. The format of a fragmented packet is:

<table>
<thead>
<tr>
<th>Bluetooth® LE packet</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMBER header</td>
</tr>
<tr>
<td>Sequence number</td>
</tr>
<tr>
<td>Fragment ID</td>
</tr>
<tr>
<td>Payload</td>
</tr>
<tr>
<td>1 Byte</td>
</tr>
<tr>
<td>1 Byte</td>
</tr>
<tr>
<td>1 Byte</td>
</tr>
<tr>
<td>$(\Phi_{ST} - 2)$ Bytes</td>
</tr>
</tbody>
</table>

Table 3: Bluetooth® LE packet format of a fragmented packet

where:

**AMBER header** is 0x04 (RF_HEADER_TYPE_FRAGDATA), guaranteeing that the fragmented packet can be distinguished from a standard packet with header 0x01 (RF_HEADER_TYPE_DATA).

**Sequence number** is a random number, that has to be the same for all fragments of a fragmented packet, but should differ for each packet.
Fragment ID is of the structure 0xAB and will define the order of the fragments to be de-
dfragmented/combined again

A the first 4 bits define the current fragment number (starting with 1)
B the last 4 bits define the overall number of fragments

2.2.1 Example: Transmitting fragmented data

Let us assume that we have a fragment payload size of 5 Bytes, the random number has been chosen as 0x00 and we suppose to send data consisting of 12 Bytes 0xE1 - 0xEC. Then 3 fragments of the following structure have to be transmitted:

<table>
<thead>
<tr>
<th>AMBER header</th>
<th>Sequence number</th>
<th>Fragment ID</th>
<th>Payload</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x04</td>
<td>0x00</td>
<td>0x13</td>
<td>0xE1 0xE2 0xE3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0xE4 0xE5</td>
</tr>
</tbody>
</table>

Table 4: Fragment 1

<table>
<thead>
<tr>
<th>AMBER header</th>
<th>Sequence number</th>
<th>Fragment ID</th>
<th>Payload</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x04</td>
<td>0x00</td>
<td>0x23</td>
<td>0xE6 0xE7 0xE8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0xE9 0xEA</td>
</tr>
</tbody>
</table>

Table 5: Fragment 2

<table>
<thead>
<tr>
<th>AMBER header</th>
<th>Sequence number</th>
<th>Fragment ID</th>
<th>Payload</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x04</td>
<td>0x00</td>
<td>0x33</td>
<td>0xEB 0xEC</td>
</tr>
</tbody>
</table>

Table 6: Fragment 3

When receiving fragmented data packets with header 0x04, the fragments are combined and output by a CMD_DATA_IND message on the UART only if:

• all fragments have been received
• all fragments have the same overall number of fragments number (B, i.e. the last 4 bits of the Fragment ID)
• all fragments contain the same sequence number

In a case where at least one of this conditions is not satisfied the data will be discarded without further notice.
3 Throughput test

This chapter describes the throughput tests that have been performed. The following devices have been tested:

- Proteus-II in FW version 1.1.0
- Proteus-III in FW version 1.1.0

3.1 Test conditions

To get the best throughput performance we choose the following settings of the Proteus module:

- The Proteus module operates in command mode.
- The UART runs with maximum baudrate (Proteus-II: 921600 Baud, Proteus-III: 1000000 Baud), 8n1, and uses the flow control pins RTS and CTS.
- The connection interval has been set to a fast value depending on the devices used (see chapter 3.3).
- Set the module to high throughput mode by setting the corresponding bit in the CfgFlags.
- The 2 Mbit mode PHY was used for transmission.

In case of using two Proteus modules for the throughput test, both modules must be configured as described.

3.2 Test procedure

The test procedure is as follows:

1. Setup a Bluetooth connection between the two Bluetooth® LE enabled devices. We call them here device A to device B.

2. Check if large data packets are supported, by reading the maximum transmission unit (MTU) from the CMD_CHANNELOPEN_RSP message during connection setup. The maximum supported data packets $\Phi_{ST}$ are:
   a) Proteus to Proteus: $\Phi_{ST} = 243 \ (0xF3) \ Bytes$
   b) Proteus to Android device: $\Phi_{ST} = 243 \ (0xF3) \ Bytes$
   c) Proteus to iOS device: $\Phi_{ST} = 181 \ (0xB5) \ Bytes$

3. Switch the PHY to 2 Mbit using the CMD_PHYUPDATE_REQ command.

4. Iterate over:
a) Transmit a data packet of maximum size $\Phi_{HTM}$ Bytes using a CMD_DATA_REQ command. $\Phi_{HTM}$ calculates as:

i. Proteus to Proteus: $\Phi_{HTM} = (243 - 3 + 1) / 4 = 964$ Bytes

ii. Proteus to Android device: $\Phi_{HTM} = (243 - 3 + 1) / 4 = 964$ Bytes

iii. Proteus to iOS device: $\Phi_{HTM} = (181 - 3 + 1) / 4 = 716$ Bytes

b) Wait for the transmission success message (CMD_TXCOMPLETE_IND) that is returned on the UART as result of the previous transmission request.

### 3.3 Test results

The throughput tests have been performed in two different test setups.

#### 3.3.1 Test setup 1: Via USB interface and PC

The Proteus modules are connected via FTDI-chip and USB cable to a PC. A PC tool triggers the repeated data transmission. In this case the USB latencies slow down the data transmission.

<table>
<thead>
<tr>
<th>Device A</th>
<th>Device B</th>
<th>Connection interval [ms]</th>
<th>Throughput [kBytes/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proteus-II</td>
<td>Proteus-II</td>
<td>8 - 8</td>
<td>24.7</td>
</tr>
<tr>
<td>Proteus-II</td>
<td>Proteus-II</td>
<td>8 - 30</td>
<td>16</td>
</tr>
<tr>
<td>Proteus-II</td>
<td>Proteus-II</td>
<td>20 - 75</td>
<td>6.3</td>
</tr>
<tr>
<td>Samsung Galaxy S8 (SM-G950F, Android 8.0)</td>
<td>Proteus-II</td>
<td>8 - 8</td>
<td>18.1</td>
</tr>
<tr>
<td>Samsung Galaxy S8 (SM-G950F, Android 8.0)</td>
<td>Proteus-II</td>
<td>8 - 30</td>
<td>11.28</td>
</tr>
<tr>
<td>Samsung Galaxy S8 (SM-G950F, Android 8.0)</td>
<td>Proteus-II</td>
<td>20 - 75</td>
<td>9.7</td>
</tr>
<tr>
<td>iPhone 7 (MN922 ZD/A, iOS 11.4)</td>
<td>Proteus-II</td>
<td>8 - 30</td>
<td>8.125</td>
</tr>
<tr>
<td>iPhone 7 (MN922 ZD/A, iOS 11.4)</td>
<td>Proteus-II</td>
<td>20 - 75</td>
<td>8.125</td>
</tr>
</tbody>
</table>

Table 7: Test results Proteus-II via USB
### Table 8: Test results Proteus-III via USB

<table>
<thead>
<tr>
<th>Device A</th>
<th>Device B</th>
<th>Connection interval [ms]</th>
<th>Throughput [kBytes/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proteus-III</td>
<td>Proteus-III</td>
<td>8 - 8</td>
<td>21.3</td>
</tr>
<tr>
<td>Proteus-III</td>
<td>Proteus-III</td>
<td>8 - 30</td>
<td>15.9</td>
</tr>
<tr>
<td>Proteus-III</td>
<td>Proteus-III</td>
<td>20 - 75</td>
<td>6.3</td>
</tr>
<tr>
<td>Samsung Galaxy S8 (SM-G950F, Android 8.0)</td>
<td>Proteus-III</td>
<td>8 - 8</td>
<td>18.9</td>
</tr>
<tr>
<td>Samsung Galaxy S8 (SM-G950F, Android 8.0)</td>
<td>Proteus-III</td>
<td>8 - 30</td>
<td>8</td>
</tr>
<tr>
<td>Samsung Galaxy S8 (SM-G950F, Android 8.0)</td>
<td>Proteus-III</td>
<td>20 - 75</td>
<td>6.16</td>
</tr>
<tr>
<td>iPhone XS (iOS 12.2)</td>
<td>Proteus-III</td>
<td>8 - 30</td>
<td>8.7</td>
</tr>
<tr>
<td>iPhone XS (iOS 12.2)</td>
<td>Proteus-III</td>
<td>20 - 75</td>
<td>8.2</td>
</tr>
</tbody>
</table>

### 3.3.2 Test setup 2: Via micro controller

The Proteus modules’ UARTs are directly connected to a micro controller\(^2\), that triggers the repeated data transmission.

### Table 9: Test results Proteus-II via micro controller

<table>
<thead>
<tr>
<th>Device A</th>
<th>Device B</th>
<th>Connection interval [ms]</th>
<th>Throughput [kBytes/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proteus-II</td>
<td>Proteus-II</td>
<td>8 - 8</td>
<td>32.17</td>
</tr>
<tr>
<td>Proteus-II</td>
<td>Proteus-II</td>
<td>8 - 30</td>
<td>16.07</td>
</tr>
<tr>
<td>Proteus-II</td>
<td>Proteus-II</td>
<td>20 - 75</td>
<td>6.78</td>
</tr>
<tr>
<td>Samsung Galaxy S8 (Model SM-G950F, Android 8.0)</td>
<td>Proteus-II</td>
<td>8 - 8</td>
<td>28.60</td>
</tr>
<tr>
<td>Samsung Galaxy S8 (Model SM-G950F, Android 8.0)</td>
<td>Proteus-II</td>
<td>8 - 30</td>
<td>16.07</td>
</tr>
<tr>
<td>Samsung Galaxy S8 (Model SM-G950F, Android 8.0)</td>
<td>Proteus-II</td>
<td>20 - 75</td>
<td>9.93</td>
</tr>
<tr>
<td>iPhone 7 (MN922 ZD/A, iOS 11.4)</td>
<td>Proteus-II</td>
<td>8 - 30</td>
<td>12.13</td>
</tr>
<tr>
<td>iPhone 7 (MN922 ZD/A, iOS 11.4)</td>
<td>Proteus-II</td>
<td>20 - 75</td>
<td>11.21</td>
</tr>
</tbody>
</table>

\(^2\)In this test a STM32 on a NUCLEOL476RG has been used.
<table>
<thead>
<tr>
<th>Device A</th>
<th>Device B</th>
<th>Connection interval [ms]</th>
<th>Throughput [kBytes/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proteus-III</td>
<td>Proteus-III</td>
<td>8 - 8</td>
<td>42.9</td>
</tr>
<tr>
<td>Proteus-III</td>
<td>Proteus-III</td>
<td>8 - 30</td>
<td>16.43</td>
</tr>
<tr>
<td>Proteus-III</td>
<td>Proteus-III</td>
<td>20 - 75</td>
<td>6.75</td>
</tr>
<tr>
<td>Samsung Galaxy S8 (Model SM-G950F, Android 8.0)</td>
<td>Proteus-III</td>
<td>8 - 8</td>
<td>28.69</td>
</tr>
<tr>
<td>Samsung Galaxy S8 (Model SM-G950F, Android 8.0)</td>
<td>Proteus-III</td>
<td>8 - 30</td>
<td>16.07</td>
</tr>
<tr>
<td>Samsung Galaxy S8 (Model SM-G950F, Android 8.0)</td>
<td>Proteus-III</td>
<td>20 - 75</td>
<td>6.30</td>
</tr>
<tr>
<td>iPhone XS (iOS 12.2)</td>
<td>Proteus-III</td>
<td>8 - 30</td>
<td>11.95</td>
</tr>
<tr>
<td>iPhone XS (iOS 12.2)</td>
<td>Proteus-III</td>
<td>20 - 75</td>
<td>11.95</td>
</tr>
</tbody>
</table>

Table 10: Test results Proteus-III via micro controller
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a failure of the product is reasonably expected to cause severe personal injury or death, unless the parties have executed an agreement specifically governing such use. Moreover, Würth Elektronik eiSos GmbH & Co. KG products are neither designed nor intended for use in areas such as military, aerospace, aviation, nuclear control, submarine, transportation (automotive control, train control, ship control), transportation signal, disaster prevention, medical, public information network etc. Würth Elektronik eiSos GmbH & Co. KG must be informed about the intent of such usage before the design-in stage. In addition, sufficient reliability evaluation checks for safety must be performed on every electronic component, which is used in electrical circuits that require high safety and reliability function or performance. By using Würth Elektronik eiSos GmbH & Co. KG products, the customer agrees to these terms and conditions.
6 License terms

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You are responsible for using the Würth Elektronik eiSos wireless connectivity product with the incorporated Firmware in compliance with all applicable product liability and product safety laws. You acknowledge to minimize the risk of loss and harm to individuals and bear the risk for failure leading to personal injury or death due to your usage of the product.

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design-in stage. In certain customer applications requiring a very high level of safety and in which the malfunction or failure of an electronic component could endanger human life or health, you must ensure to have all necessary expertise in the safety and regulatory ramifications of your applications. You acknowledge and agree that you are solely responsible for all legal, regulatory and safety-related requirements concerning your products and any use of Würth Elektronik eiSos’ products with the incorporated Firmware in such safety-critical applications, notwithstanding any applications-related information or support that may be provided by Würth Elektronik eiSos. YOU SHALL INDEMNIFY WÜRTH ELEKTRONIK EISOS AGAINST ANY DAMAGES ARISING OUT OF THE USE OF WÜRTH ELEKTRONIK EISOS’ PRODUCTS WITH THE INCORPORATED FIRMWARE IN SUCH SAFETY-CRITICAL APPLICATIONS.

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6.8 Severability clause

If a provision of this license terms is or becomes invalid, unenforceable or null and void, this shall not affect the remaining provisions of the terms. The parties shall replace any such provisions with new valid provisions that most closely approximate the purpose of the terms.

6.9 Miscellaneous

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By ordering a wireless connectivity product, you accept this license terms in all terms.
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Monitoring & Control
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