Encoding sensor data in Bluetooth Low Energy MSD field as a means of reducing energy consumption

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***Abstract*— In this paper a case study of Bluetooth 4.0 sensor network is presented, which features an improved energy performance due to including the sensor data into the advertising packets of the peripheral device so that the subsequent connection becomes unnecessary. By using the presented technique, a reduction in energy consumption of approximately 40%, as compared with the usual communication mode, was experimentally verified with a built proof-of-concept BLE network comprising different sensors.**

Keywords—Bluetooth Low Energy, Wireless Sensor Network

I. INTRODUCTION

A Bluetooth Low Energy, or BLE, device can play four different roles, namely broadcaster, observer, peripheral and central. As broadcaster, the device operates as a data transmitter only, broadcasting data periodically. This action is named Advertising and the data the device transmits when it executes this action basically comprises information of it and indicates its presence as well. The data is transmitted in packets, which are named advertising packets [1].

When the device plays observer, it operates as a data receiver only, and listens to advertising packets that are transmitted by devices that operate as broadcasters at the time [1].

In the role of peripheral, a device can establish a connection as a BLE slave, upon being detected by another device. In order to be detected by another device, however, a peripheral device must have announced its presence, operating as a broadcaster, before the connection takes place [1].

When the device plays the role of central, it supports the establishment of one or more connections as a BLE master, and the central is responsible for initiating the connection. In order to detect a nearby peripheral, the central device must operate as an observer [1].

A BLE device can play one or more roles at the same time if it has enough resources for that [1].

The exchange of data among devices is usually done through a BLE connection [2], which will drain energy to keep the connection packets transmission and results in an energetic cost that may not be tolerable depending on the application.

However, the advertising packets of a device also may contain data which can be encoded according with the predefined data structures listed in the Bluetooth Assigned Numbers. One exception is the Manufacturer Specific Data field, a field which is defined without a data structure, allowing an application to use its own data structure on advertising [3][4].

II. ADVERTISING PACKET STRUCTURE

Advertising packets are composed by a 16 bits header and a payload with a variable length from 6 to 37 bytes. An advertising payload contains 6 bytes for device address and up to 31 bytes of advertising data, as shown in the fig. 1 [1].

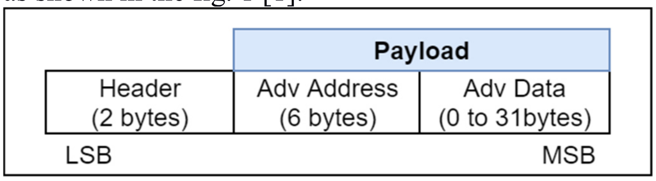

Fig. 1 – Structure for Advertising Packets [1]

An advertising data field has the following structure shown in the fig. 2: the first byte defines the length of the advertising data; the second byte contains the advertising data type, and the following bytes represents the advertising data [1].

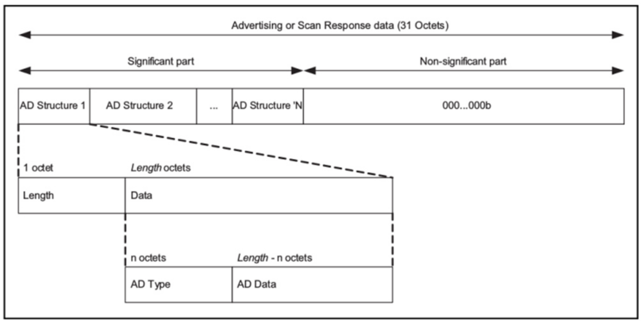

Fig. 2 – Advertising Data Structure [1]

The advertising payload may contain one or more advertising data fields which will fit in the 31 reserved bytes and must be composed according to the corresponding data type [1].

A. Advertising Data Types

Advertising data type is a value represented by one byte matching the Advertising Data Types table available in the Bluetooth Assigned Numbers document [4]. Each type defines both content and structure for an advertising data packet. For instance, the Complete Local Name data type, defined with the value 0x09h for data type field, is composed as a string containing the full device name [3].

B. Manufacturer Specific Data

Manufacturer specific data, also named MSD, is a data type with an open structure, allowing companies and institutions to build their own data structures and transmit them in advertising packets. This data type contains a Company ID composed by two bytes which are managed by the Bluetooth Special Interest Group and are available in the assigned numbers page [5].

Any desirable data needed by a custom application may be encoded in this field allowing devices to transmit data which is not predicted in the BLE specification by default [3]. Therefore, the MSD field is a possibility to unveil new options of optimization by encoding data that was intent to be transmitted through a connection in the advertising packets. This possibility is applicable for unidirectional data flow when the designed peripheral device doesn't need to receive data from a device playing the central role.

III. SENSOR NETWORK DESIGN

During a connection, an intense exchange of data packets occurs to keep the link between the devices and this exchange of packets has a significant energetic cost. The data transmission strategy proposed in this work aims at to save power by avoiding the above described connection phase.

The proposed wireless sensor network design consists of a sensor node collecting and encoding environmental data in advertising packets using the MSD data type filled with a data structure that features defined bytes for each measured variable.

A BLE connection for configuration purposes is also desirable. Since a sensor network spends most of its time measuring and transmitting sensor data, the configuration events are not frequent, allowing this possibility without compromising the device energetic performance and offering a more dynamic operation for the sensor node.

IV. ENERGY CONSUMPTION ANALYSIS

A. Prototype

For this case study a prototype was developed based o nRF51822 SoC with a TSL2561 luminosity sensor and a HTU21D temperature and humidity sensor. Using the sensors breakout boards and the development kit BLE400 for nRF51822, which also can be replaced by nRF51 PCA10028 Development Kit, the prototype was assembled as shown in the fig. 3.

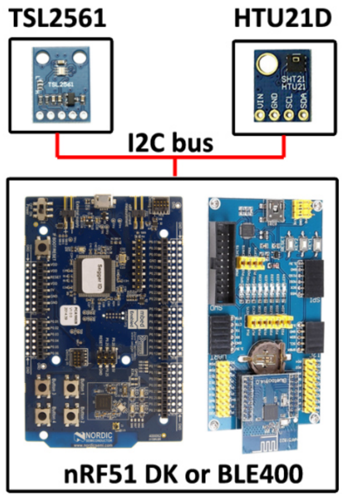

Fig. 3 - Prototype components

The developed firmware, available at [6] offers a BLE profile which allows a central device to configure and receive the sensor data streaming through a connection. Sensor data is also encoded in advertising packets as a Manufacturer Specific Data field using the following the structure defined in table 1, which shows all the advertising data. The chosen Company ID was the Nordic Semiconductor's ID, the SoC manufacturer, defined as 0x0059h. Pressure data infrastructure is provided in the advertising data structure, but not included in the prototype because the pressure sensor was unavailable by the time of the tests.

TABLE 1 – PROTOTYPE'S ADVERTISING DATA FIELD

Data Type	Octet	Data	Value
Flags	0	Flags size	0x02
	1	Flags data type	0x01
	2	Flags	0x06
MSD	3	MSD Size	0x13
	4	Data Type	0xFF
	5..8	Nordic's Company ID	0x0059
	9..12	Pressure Data (4 bytes)	From sensor
	13..14	Temperature Data (2 bytes)	From sensor
	15..16	Humidity Data (2 bytes)	From sensor
	17..20	Visible luminosity data (4 bytes)	From sensor
	21..24	Infrared luminosity data (4 bytes)	From sensor

Data is advertised as long as the device is not connected. When a connection is started, the device plays only as a peripheral and stops advertising.

In this scenario, the advertising interval is configured to transmit data every 1000ms, the sensors are also sampled every 1000ms and the radio TX power is set to –12dB.

In order to evaluate the energy consumption performance of the system, a shunt current meter was connected to the prototype and the current waveforms could be seen on the oscilloscope.

B. Connection

The connection with the prototype was managed by Nordic Semiconductor's nRF Connect app in an Android smartphone, which connects to the prototype and receive sensor data. The default configuration of the app was used for the BLE connection.

The obtained current waveform during the connect state is shown in Fig. 4. Using the corresponding CSV file from the oscilloscope, the calculated average current value was 127.9uA.

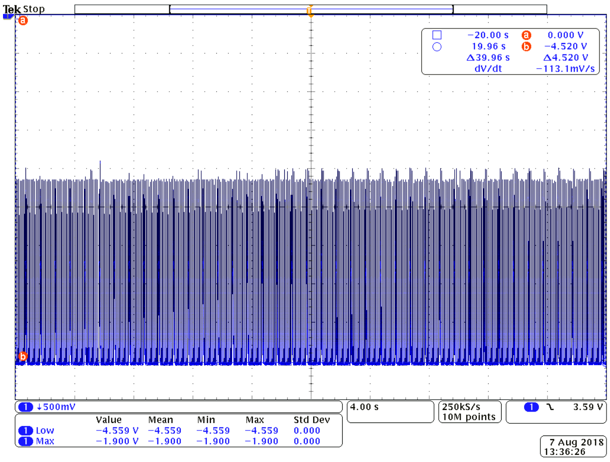

Fig. 4 - Current waveform for connected state

C. Advertising

Advertising data was verified by the same app. Playing as a broadcaster, the prototype's acquired waveform is displayed in fig. 5. In this case, the average current was 80.79µA, thus showing a reduction in consumption of circa 40%.

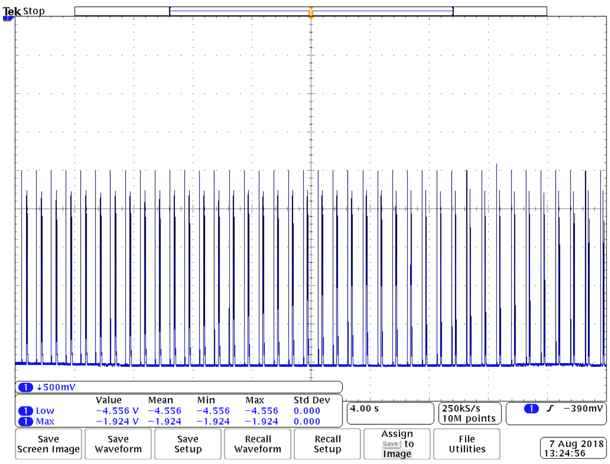

Fig. 5 - Current waveform for unconnected state

In the waveform of fig. 5 it can be seen that there are two different shapes of current peaks. These two shapes are zoomed in fig. 6. The one to the left corresponds to the sensor data acquiring and the other to advertising. A detailed waveform for the advertising event is shown in the fig.8.

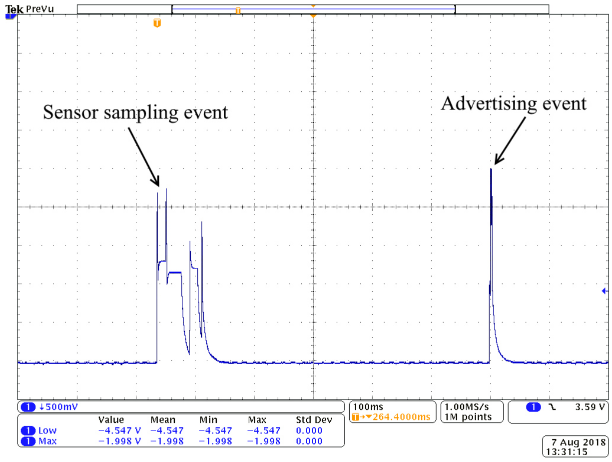

Fig. 6 - Current waveform for unconnected state

D. Comparison

Fig. 7 shows the current waveform for a connection event. The difference between the densities of transmitted packets when connected and when unconnected is remarkable.

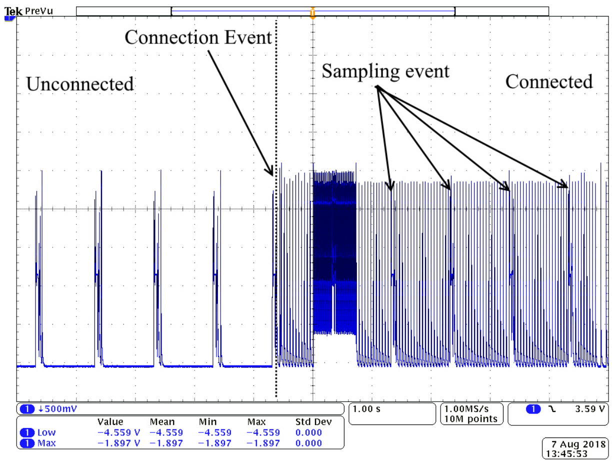

Fig. 7 - Connection event

There is a difference between the packets during the advertising and the connection. The advertising packets are transmitted in 3 different channels, resulting in the waveform displayed in the fig. 8. The connection packets are transmitted in one channel at time, as shown in the fig. 9.

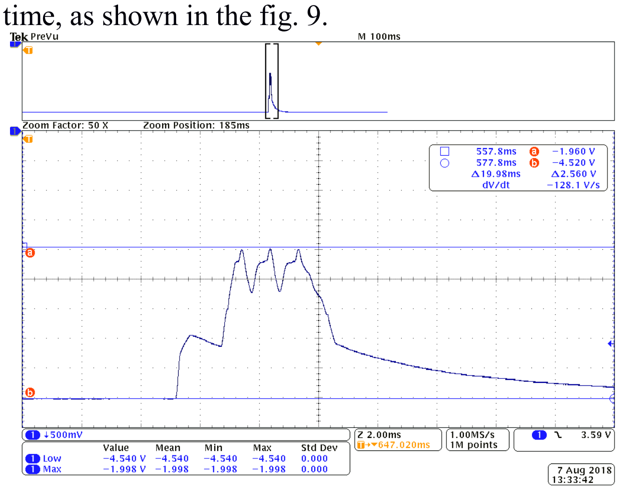

Fig. 8 - Advertising packet transmission

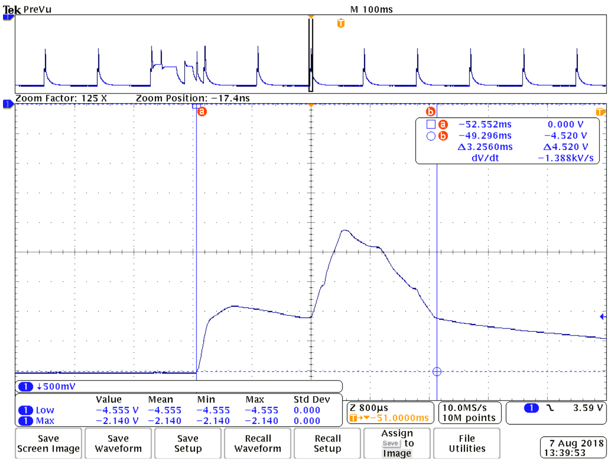

Fig. 9 - Connection packet transmission

Although the advertising packets are transmitted 3 times, the average current during the unconnected state is 80.79uA while the connected average current is 127.9µA. This is the particular feature that motivated the presented work.

V. CONCLUSION

Using advertising to transmit sensor data was proved to be more efficient than connection, regarding energy consumption. In the tested scenario, the current consumption dropped from 127.9µA to 80.79µA representing a reduction of 40%. This result will certainly change for another radio configuration, sampling rate and data throughput which might either increase or decrease the current consumption.

The disadvantages found in this mode of sensor data transmission are: a possible increase in the data delivery error, since an advertising packet does not demand any acknowledgment from other devices; and an increase in current consumption proportional to data transmission rate.

As a remedy to these possible shortcomings, it is important to mention that variables like signal range, data sampling interval and data throughput have significant influences in the energy consumption and they can be adjusted to reduce possible losses.

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