Journal of Universal Computer Science, vol. 19, no. 9 (2013), 1219-1241
submitted: 22/2/13, accepted: 2/4/13, appeared: 1/5/13 © *J.UCS*

Evaluation of Bluetooth Low Energy Capabilities for Tele-mobile Monitoring in Home-care

Antonio J. Jara, David Fernandez, Pablo Lopez, Miguel A. Zamora and Antonio F. Skarmeta
(Clinical Technology Lab (CLITech)
Research Institute for Oriented Inf. and Com. Tech. (INTICO)
Computer Sciences Faculty, University of Murcia
Reg. Campus of Int. Excellence "Campus Mare Nostrum"
Murcia, Spain
{jara, david.f.r, p.lopezmartinez, mzamora, skarmeta}@um.es)

Leandro Marin
(Department of Applied Mathematics
Computer Sciences Faculty, University of Murcia
Reg. Campus of Int. Excellence "Campus Mare Nostrum"
Murcia, Spain
leandro@um.es)

Abstract: Bluetooth Low Energy (BLE) is extending Bluetooth technology to devices with lower communication requirements and higher constraints in terms of memory capabilities and power autonomy. Thereby, BLE makes feasible the wireless transmission of information from smart objects such as wearable clinical devices, ambient sensors and actuators. These smart objects are starting to be internet-enabled devices, reaching the so denominated Internet of Things (IoT). Our research work is focused on analyze the capabilities of these technologies for continuous data transmission and integration of clinical sensors in home-care and Ambient Assisted Living environments. For this purpose, this work analyses exhaustively the capabilities from BLE and compare this with the capabilities from Bluetooth 2.1. In addition, it has been considered the communications requirements from different clinical devices such as an electrocardiogram (ECG) and a capnograph. It is concluded that the performance from BLE is lower than Bluetooth Classic (Bluetooth 2.1) for continuous communications, since BLE is based on attributes (datapoints) transfer instead of offering a communication session where can be transmitted as much packets as required, without any size constraint. Therefore, it is necessary to perform data compression/aggregation when the amount of data to send is too large to be stored in a BLE attribute. This work also presents how to apply pre-processing techniques that greatly reduces the transmission overload (performs signal compression) in order to allow the continuous transmission of the ECG and capnograph signal through BLE making so feasible the integration of continuous clinical devices via BLE.

Key Words: Bluetooth Low Energy, performance assessment, mobile communications, tele-monitoring, mobile monitoring, clinical technology, continuous data transmission, performance, Internet of Things, electrocardiogram
Category: C.2, C.3, J.3, L.7, L.7.0

1 Introduction

Flexibility, ubiquity, global access capabilities and mobility support are the features from the Future Internet that can be find on the new generation of technologies based on the Internet of Things (IoT). Thereby, IoT provides the capabilities to collect a large amounts of data with higher accuracy and context awareness. These reasons are why IoT is considered one of the greatest advances in communications from the recent years for the development of autonomous applications and services that enable make a more a scalable operation and maintenance. Currently, there are several works in areas such as home automation [Zamora et al. 2010], intelligent transportation systems [Castro et al. 2011] and personalized healthcare [Istepanian et al. 2010].

IoT is empowered by the mobile computing through the new generation of personal devices, smart phones in conjunction with the evolution of wireless communication interfaces in these mobile platforms [Orlando et al. 2011]. Nowadays, several wireless communications platforms can be located in the mobile phones such as WiFi, Bluetooth classic and the emerging Near Field Communication (NFC) and Bluetooth Low Energy (BLE).

These communication technologies are making feasible to extend the Internet to small sensors and devices, in order to identify and connect all the things, people and systems. For example, this evolution allows to communicate with systems located at their bedroom [Choi et al. 2004] or such as mentioned with personal devices such as smart phones.

The different devices and sensors that are being integrated in the IoT present a wide heterogeneity in terms of functionality and communication requirements. On the one hand, discrete sensors which transmit a discrete value each several seconds, hours or even days, on the other hand, continuous sensors with high requirements to support continuous data transmission, such as electrocardiogram and capnography, which present high communications requirements and challenges since the new transmissions technologies are designed for low consumption through a limited payload size and bandwidth.

In particular, the use cases addressed in this work for tele-mobile monitoring in home-care and Ambient Assisted Living environments use devices with a wide range of communication requirements.

In healthcare sector are distinguished two families or clinical devices, on the one hand, discrete clinical devices which are used periodically such as the blood pressure monitor, weight scale, and glucometer. These devices are being historically integrated with low power wireless personal area networks such as ZigBee and Bluetooth [Continua 2009]. On the other hand, continuous clinical devices with a medium complexity such as the pulse oximeter are being also integrated through ZigBee and Bluetooth technologies, and devices with higher complexity such as the electrocardiogram (ECG) has been integrated with a reduced sampling frequency, since the original sampling frequency presents higher requirements that these technologies were assumed to support.

In particular, Continua Alliance, which is an alliance of clinical devices manufacturer and vendors to ensure the interoperability among personal health and wellness devices, has defined profiles for several technologies. In the case of Bluetooth, Continua Alliance has defined the Bluetooth Health Device Profile (HDP). HDP provides a reliable and secure transport for transmitting sensitive information over a Bluetooth link. Application level protocol is defined very well with IEEE 1073 standards that provide device interoperability between different vendors [Carroll, Randy, et al. 2007]. At the same way it has been also defined for ZigBee. However, for Zigbee some clinical devices such as ECG has not been yet released following the IEEE 1073 standard because its complexity in terms of communications requirements. For that reason, the most common devices compliant with the IEEE 1073 family of standards available on the market are blood pressure monitor, weight scale, glucometer, and pulse oximeter

This work has chosen an ECG, among the several continuous sensors available to study, due both its complexity and its great clinical relevance for healthcare environments. Concretely, the simple continuous sensor ECG used to perform this work is the EG 01000 from MedLab presented in the Figure 3, which provides a continuous data channel through a serial interface. Specifically, the wave received from the ECG is the V2, which contains relevant information to perform diagnosis about the patient hearth status.

Previous work, based on 6LoWPAN [Jara et al. 2011a, Jara et al. 2013a] and NFC [Jara et al. 2011b, Jara et al. 2013b], in conjunction with the current work complete the study for the three main transmission technologies available for IoT. Each technology has different purposes, capabilities, hardware and protocol stack. For example, NFC allows elderly people and caregivers get benefit from its ease of use with contactless communications to establish a link approaching the clinical devices, e.g., glucometer, to personal devices, e.g., smart phones.

BLE extends Wireless Personal Area Networks to use cases more relevant for nurses, physician and caregivers, because they can exchange information with the patient without the needs to approach their personal device to the clinical device, instead they can communicate in a coverage of several meters. Thereby, allowing to collect the data standing around the room or near by the patient.

In addition, the use of the mentioned technologies can be combined. For example, NFC to identify the caregiver or make the pairing/binding between the sensor and the device. 6LoWPAN for the transmission in large ranges carrying the information to the gateway that permit us connect small object and sensors to Internet, and finally Bluetooth for personal area communications, i.e. communication with personal devices.

This work is focused on BLE evaluation. Section 2 describes the communication capabilities from BLE technology. Section 3 presents the requirements from the continuous data transmission model. Section 4 presents the evaluation carried out with Bluetooth 2.1 and BLE. Section 5 presents the results from the evaluation. Finally, Section 6 presents the discussion about the feasibility of BLE for continuous communication in tele-mobile monitoring and Section 7 concludes the paper specifying the future work.

2 Bluetooth Low Energy

BLE presents an interesting alternative technology for the IoT. This has optimized the communications for small and discrete data transfers, as a difference with respect to the classic Bluetooth that was mainly defined for continuous communications such as audio and voice in headsets and mobile phones.

BLE has been designed taking into account the requirements from Machine to Machine (M2M) communication and IoT, e.g., sensors that require only transmit some data or attribute sporadically. For this purpose, this allows to transmit data without the requirement to establish a connection, thereby, the delay from pairing and establishing communication is removed, in numbers, it has evolved from the initial over 100 milliseconds to establish the communication and transmit the data to a time under 3 milliseconds. Therefore, sensors are able to stay sleeping and just wake-up few milliseconds to transmit data periodically or because a particular event. Thanks to this feature BLE is presented as the best alternative for applications that require a long lifetime and they will be the majority of the time sleeping.

The functions offered by BLE goes from provide regularly update data, e.g., clinical and wellness devices; request data, e.g., smart light; control other devices, e.g., smart meters and pill dispensers; and finally managements with support for load applications over the air for remote management and subscription functions to receive updates and maintenance.

The main differences are presented in the Table 1. Bluetooth Low Energy has simplified several issues from Bluetooth Classic in terms of implementation complexity. For example, Bluetooth Low Energy has removed the support of scatternet and piconet topology, leaving only the support for star topology.

The memory requirements has been reduced presenting a small footprint. For this purpose the number of packet types has been reduced from 13 packet types (5 mandatory) in Bluetooth Classic to a common packet structure with only 2 packet types, one for advertising and other for data communication. The number of control messages has been also reduced from 75 LMP messages to 8 LL messages. Finally, the communication profile has been reduced from 9 protocols (RFCOMM, BNEP, AVCTP, AVDTP, HCRP, TCSBIN, MCAP, OBEX, HID, SDP) to only 1 protocol based on attributes.

Table 1: Time delay measures for both vital signs transmission modes.

Technical Specification	**Bluetooth 2.1**	**Bluetooth Low Energy**
Radio Frequency	2.4 GHz	2.4 GHz
Coverage Range	∼10-100 m	∼50 m
Symbol Rate	1-3 Mbps	1 Mbps
Application Throughput	0.7-2.1 Mbps	305 kbps
Nodes connected (slaves)	7	Unlimited
Security	56 to 128 bits	128 bits AES
Robustness	FHSS	FHSS
Latency (sleep to send)	>100 ms	<3 ms
Robustness	FHSS	FHSS
Voice Capable	Yes	No
Power Consumption	1 (reference)	0.01 to 0.5 (use case)
Peak Current Consumption	<30 mA	<18 mA
Topology	Scatternet	Star
Service Discovery	Yes	Yes
Application Profiles	Yes	Yes
Protocols	9 (RFCOMM, SDP, etc.)	1 (Attribute)
Control Messages	75 LMP messages	8 LL control messages
Packet types	5 mandatory	2 (Advertisement / Data)
Use cases	Mobile phones, headsets, stereo audio, clinical, automative, etc.	Mobile phones, wellness, clinical, home electronics, Internet of Things, etc.

The attribute protocol is a connectionless protocol. Therefore, no memory is required to store the state and offer an efficient protocol to exchange values.

Attribute protocol also brings serious limitations. For example, this reduction to implement everything as an attribute that can be read or written present several limitation for continuous communications.

The robustness is similar to Bluetooth classic since this continues supporting Frequency Hopping Spread Spectrum (FHSS).

The security is similar to IEEE 802.15.4 and other Wireless Low Power technologies, this support AES 128 bits, which is a very extended security standard which is nowadays used in WPA2 for WiFi and it has been also considered a primitive for high level security protocols such as Datagram Transport Layer Security (DTLS) for UDP packets [Rescorla, E. and Modadugu, N. 2012].

BLE has been specially designed to reach a low power consumption. This is reduced with respect to Bluetooth Classic and other low power technologies such as 6LoWPAN. The optimizations from BLE to reach a low power consumption are focused on a simplified advertising protocol in order to simplify the scan

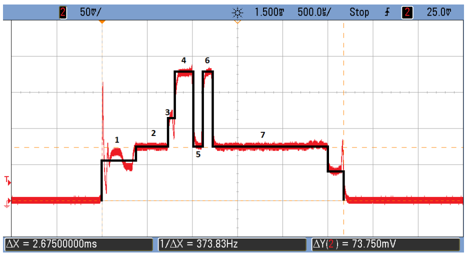


Figure 1: Bluetooth Low Energy consumption for a single frame [Kamath, S. and Lindh, J. 2012].

and required stand by time before transmit data. This simplification has been reached reducing from the 16 available channels to only 3 channels for advertising. Previous works have already explored and demonstrated the advantages from this discovery capabilities [Campo et al. 2006].

BLE offers faster connection with the option of automatically connects to the advertising device when scanning. Specifically, the radio needs to be awake only for 0.6 to 1.2 ms for discovery and join to a network. Thereby, it is reached the mentioned under 3 milliseconds to establish connection and transmit. Thanks to this low awake period, when the duty cycle is over 0.5 seconds the radio power consumption is negligible.

BLE peak current is under the 17.5 mA threshold allowing thereby be powered with coin cell batteries. BLE uses GFSK modulation and low packet length in order to reduce the peak power during transmission and reception.

The application note of Texas Instruments [Kamath, S. and Lindh, J. 2012] presents an empirical evaluation of the BLE power consumption, Figure 1 presents the capture from the oscilloscope and the Table 2 the summary of the results. This can be concluded that the reception and transmission time is very low, in numbers, the total time is 2,675 s. This time is a consequence of offer a reduced time for wake up the radio, establish connection and transmit the data; this new feature allows to define very aggressive duty cycles to optimize the lifetime.

Regarding power consumption, BLE transceivers offer a low peak power to make feasible its integration with coin cell batteries. These features make BLE a very relevant technology to achieve low energy solutions in the next generation of embedded communications.

Table 2: Power consumption in Bluetooth Low Energy.

Phase	Time (uS)	Current (mA)
State 1 (wake-up)	400	6.0
State 2 (pre-processing)	340	7.4
State 3 (pre-Rx)	80	11.0
State 4 (Rx)	190	17.5
State 5 (Rx-to-Tx)	110	7.4
State 6 (Tx)	115	17.5
State 7 (post-processing)	1280	7.4
State 8 (pre-Sleep)	160	4.1

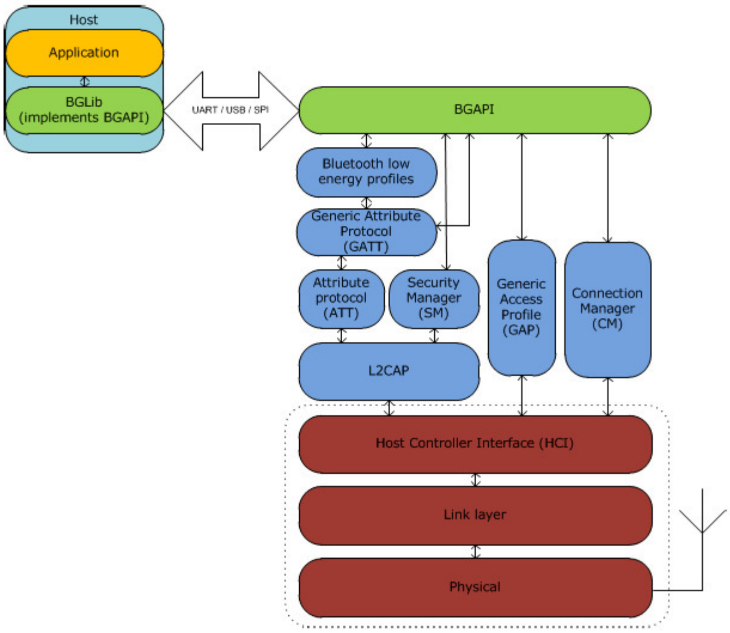


Figure 2: Bluetooth Low Energy Communication Stack.

Finally, Figure 2 presents the BLE stack. BGAPI implements the different device profiles that the vendor can define for its specific application. This device profile describe what the sensors will provide/receive in terms of attributes. These profiles are defined over the Generic Attribute Protocol (GATT) which

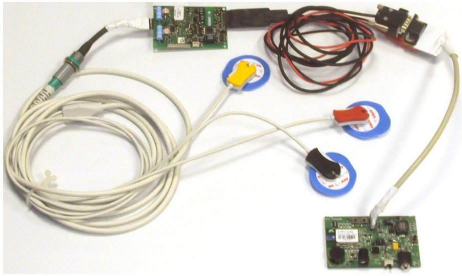


Figure 3: ECG module EG1000 from medlab.

defines how to access the data. This protocol is built over the L2CAP which is the multiplexor/fragmenter for the different packets to be transmitted to the link layer through the interface between Host and Controller (HCI).

3 Communication requirements from clinical devices

Clinical sensors present native protocols for communications, which provide RAW data from sensors formatted following a standard such as Health Level 7 (HL7) and IEEE 1073 (X73).

The original protocol of the ECG has a sampling rate of 300 samples/second (Hz), and a high resolution mode with an accuracy of 150 values per mV. Thus, let us consider a sampling frequency (ω) with a value of 300 Hz. It requires a total of ϵ bytes for each pulse for the heartbeat rate (β). For example, this requires 236 bytes for the case of 76 bpm (beats per minute), following the equation 1.

$$\frac{60\omega}{\beta} = \epsilon \tag{1}$$

4 Evaluation

The evaluation has been carried out in three different phases. First, it has been evaluated exhaustively the communication capabilities of Bluetooth 2.1. For this purpose, two evaluation modules presented in the Section 4.2 has been programmed to communicate with an exhaustive set of sizes.

Second, it has been also evaluated exhaustively the communication capabilities of BLE. In this occasion, the modules presented in the Section 4.3 have been utilized.

Finally, it is evaluated the communications with BLE in clinical devices.

4.1 Evaluation platform

This work has been carried out with the solutions from Bluegiga. The following subsections present the evaluation environment set-up with the Bluegiga modules and how the tests has been carried out.

4.2 Bluetooth 2.1

The tests has been carried out with evaluation boards based on the chip WT12. The WT12 is the Bluetooth 2.1 transceiver integrated in the clinical sensor.

The distance between them has been established to 50 cms.

The boards are connected to the PC through the serial port and using the Serial Port Profile from Bluetooth 2.0 over the RFCOMM protocol [Bluetooth 2003]. This profile is supported by the iWRAP 4 firmware of Bluegiga.

iWRAP 4 offers commands to establish the SPP connection between the both boards. The commands to establish the SPP communication are presented in the Listing 1. The command *SET BT SSP 3 0* is used to establish a Secure Simple Pairing, the command *SET BT AUTH * 0000* establishes the PIN and finally the command *SET PROFILE SPP SERIE* establishes the Serial Port Profile.

Listing 1: Bluetooth SPP connection establishment.

```
SET BT SSP 3 0
SET BT AUTH * 0000
SET PROFILE SPP SERIE
```

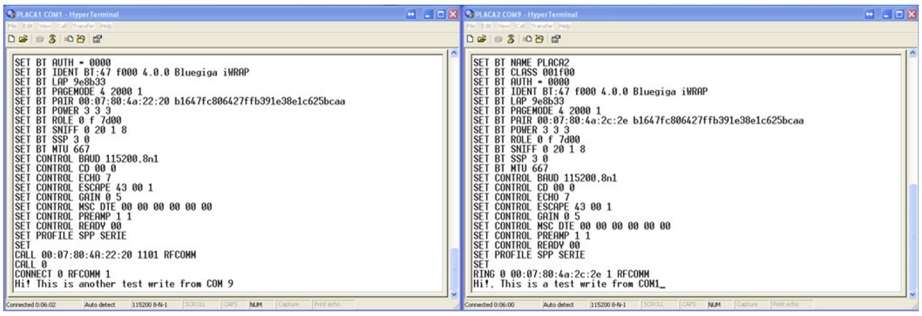


Figure 4: Bluetooth 2.1 serial communication establishment (SPP profile).

The connection is established using the call to the protocol RFCOMM on the MAC from the other device, *CALL 00:07:80:4A:22:20 1101 RFCOMM*. RFCOMM offers the capabilities to build over the L2CAP multiple communications simulating RS232 serial ports. This protocol is described in the ETSI TS

07.10 [Bluetooth 2003]. The most relevant feature to take into account for the evaluation is that the MTU is established to 667 bytes. Figure 4 presents the establishment of the communication through the mentioned commands.

Once the communication is established, two Java-based applications have been developed which are communicated with the BLE evaluation board through the serial port. The communication with the serial port is based on the *RXTX* library.

Finally, the Bluetooth 2.1 packet is formed by 72 bits for Access Code, 54 bits header and a flexible payload from 0 to 2745 bits (343 bytes) [Kim et al. 2011]. Therefore, the fragmentation is defined, on the one hand, by the RFCOMM application protocol to 667 bytes in the application level, and on the other hand, each one of these application packets will be fragmented into two L2CAP frames since the limit in the link layer (L2CAP) is 343 bytes. The payload size has been defined dynamically in order to obtain an extended range of results.

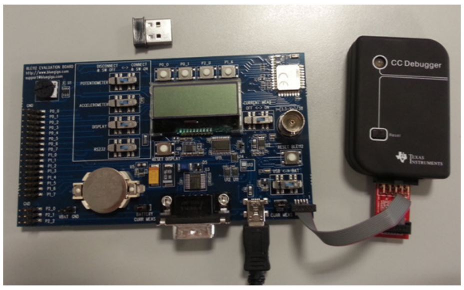


Figure 5: Bluetooth Low Energy Evaluation Board DKBLE112.

4.3 Bluetooth Low Energy

The evaluation for BLE has been carried out with the Bluegiga DKBLE112 module, presented in the Figure 5. This includes a SPI CC Debugger and a USB Dongle (BLED112). The tests has been also carried out in a distance of 50 cms to offer a similar conditions that for Bluetooth 2.1. The following subsections present in more details each one of the parts.

4.3.1 Bluegiga DKBLE112 Module

The first device used to perform the communication via BLE is the BLE112 module from Bluegiga that allows easy and fast develops of applications through the BGAPI Protocol. The module BLE112 is the BLE module integrated in the clinical device.

This device acts as slave device in the connection, where the DKBLE112 module contains a simple program developed with BGScript language to advertise his services expecting for connections. This module is used to integrate the clinical devices. Therefore, this allows to connect through a serial (UART RS232) interface the electrocardiogram.

Thereby, it is offered the data gathered from the clinical sensor in the GATT server. These values will be read by the PC enabled with BLE via a BLED112 USB Dongle.

4.3.2 USB BLED112 Dongle

The BLED112 is a single mode USB device that enables BLE connectivity for PCs and other devices having a USB port. This device acts as master, establishing the connection with DKBLE112 in order to perform the *read_attribute* call from BGAPI, this call send a BLE packet that request the attribute indicated by his handle to the GATT server. This program, that discovers the DKBLE112 device via his advertisements, establishes the connection, send a Bluetooth packet containing the *read_ attribute* command codified through BGAPI Protocol and receive the attribute value, has been developed in C language using BGLib.

4.3.3 BGAPI, BGLib and BGScript

BGAPI Protocol is a binary lightweight protocol that allows the management of BLE protocol stack through calls and events. Basically, this offers a transport protocol between the host and the Bluetooth stack in order to transmit and receive data packets. But not all is benefit; the use of BGAPI introduces his own header into the MTU, using some bytes that could be used to transmit information.

BGLib is an ANSI C host library available for easy implementation of BGAPI protocol. The library is easy portable ANSI C code delivered within the Bluetooth 4.0 single mode energy development suite. The purpose is simplifying the application development from the host side.

BGScript scripting language provides a simple way to develop simplest standalone applications into the DKBLE112 module. The other currently way to develop applications is work with a private workbench, writing the code directly on C and assembler, this option is fit onto the future work in order to reach better results but using our own hardware (Movital) [Jara et al. 2011c].

4.3.4 Differences between BLE and BGAPI Protocol

BLE Link Layer protocol defines one generic packet format used for both advertisement and data packets. It is composed by a preamble, an access address (where advertisement packets use a fixed access address of 0x8E89BED6 and data packets use a random access address depending on the connection), the protocol data unit that depends on the packet type and 24-bit CRC checksum to protect the PDU.

A BLE data packet using a simplest L2CAP mode leaves 31 bytes of payload, but the Bluegiga solution (BGAPI protocol) use a 5 bytes header, leaving only 22 bytes of payload available. The Bluegiga solution offers a simplest way to develop BLE applications but reducing the payload available. BGScript use of the payload over the stack presented in the Figure 2.

4.3.5 Attribute profile

BLE offers a profile totally different to SPP, since it is based on *Attributes*.

The evaluation has been carried out the query of attributes which are dynamically being updated continuously in order to get a simulation of continuous communication and exhaustive analysis of performance for different sizes. The time measured is the Round Trip Time (RTT).

For the evaluation it has been defined the different attributes from the services. Listing 2 presents a fragment of the attributes description file. Specifically, 9 attributes are defined with different sizes: 10, 20, 30, 40, 50, 100, 150, 200, and 250 bytes, where each attribute is represented by an UUID.

Listing 2: Attributes description

```
<?xml version="1.0" encoding="UTF-8" ?>
<configuration>

  <service uuid="1800">
  <description>Generic Access Profile</description>
  ...

  <service uuid="1809">
     <description>Values to be read</description>

         <characteristic uuid="fa1c" id="xgatt_10b_fa1c">
            <description>10bytes</description>
            <properties read="true"/>
            <value type="hex">00112233445566778899</value>
         </characteristic>

         <characteristic uuid="fa2c" id="xgatt_20b_fa2c">
            <description>20bytes</description>
            <properties read="true"/>
            <value type="hex">00112233445566778899
                00112233445566778899</value>
         </characteristic>
         ...
   </service>
</configuration>
```

In addition to the attributes it is defined the logic using the BGScript language. The file presented in the Listing 3 represents the logic from the script. The system start calling *system_boot* where is defined the advertisement mode and discoverability using the *gap_set_mode*. In addition, this allows to be *Undirected connectable* in order to get the optimization for quick connection described for BLE.

After this the attributes are updated each 660 milliseconds in order to simulate the continuous behavior from a clinical device such as the electrocardiogram. In details, *hardware_soft_timer* defines the timer callback where is called the *attributs_write* function to update the values.

Listing 3: BGScript with the logic from the program

```
event system_boot(major, minor, patch, build, ll_version,
                                    protocol_version, hw)
   call gap_set_mode(2,2)
   call hardware_set_soft_timer($5554, 1, 0)
end

event hardware_soft_timer(handle)

   if handle = 1 then
      value=value+1
      call attributes_write(xgatt_10b_fa1c,0,4,value)
      call attributes_write(xgatt_20b_fa2c,0,4,value)
      call attributes_write(xgatt_30b_fa3c,0,4,value)
      call attributes_write(xgatt_40b_fa4c,0,4,value)
      call attributes_write(xgatt_50b_fa5c,0,4,value)
      call attributes_write(xgatt_100b_fa6c,0,4,value)
      call attributes_write(xgatt_150b_fa7c,0,4,value)
      call attributes_write(xgatt_200b_fa8c,0,4,value)
      call attributes_write(xgatt_250b_fa9c,0,4,value)
   end if
end

event connection_disconnected(handle,result)
   call gap_set_mode(2,2)
end
```

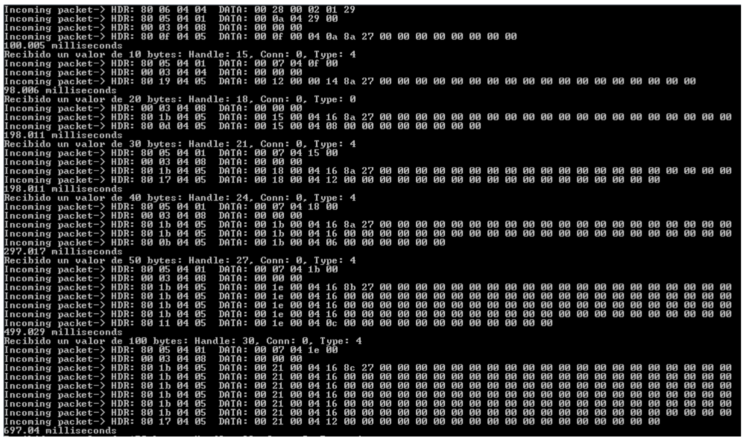


Figure 6: Bluetooth Low Energy evaluation with BGLib.

Finally, this attributes are read through the C program developed with the *BGLib*, see Figure 6. The received packets are composed by 31 bytes (non-encrypted version). This packet has 9 byfes from the BGScript header such as presented in the Figure 12, therefore the final payload is 22 bytes. For example, an attribute of 150 bytes require 7 packets of BLE.

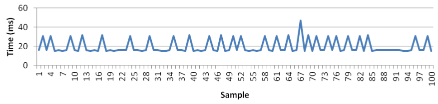
5 Results

This section presents the results from the tests carried out for Bluetooth classic (Bluetooth 2.1) and BLE.

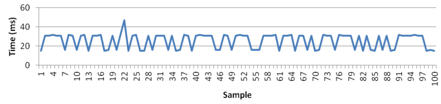
5.1 Bluetooth 2.1

Figure 7 presents exhaustively the results for 100 tests with the platforms described defining different packet sizes. Finally, it is summarized in the Figure 8 the evolution of the delay when the size is increasing.

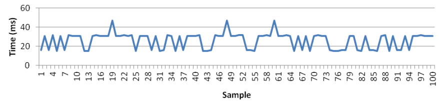
The result presents an interesting behaviour since it is not growing exponentially and some higher packet sizes present similar time that communications with a level below of size. This is mainly caused by the fragmentation described, since it is carried out two fragmentations, first in the protocol level (RFCOMM) and second in the link layer level (L2CAP). For that reason, communications of 2000 bytes and 1750 bytes present a similar requirements, since both of them require 3 RFCOMM packet (667 bytes per packet), and each RFCOMM requires 2 L2CAP frames (343 bytes).



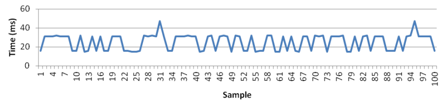
(a) 10 Bytes



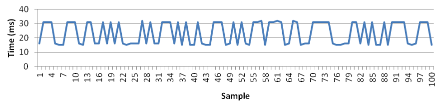
(b) 20 Bytes



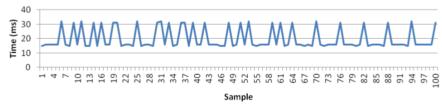
(c) 30 Bytes



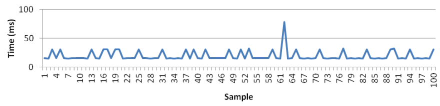
(d) 40 Bytes



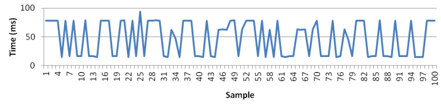
(e) 50 Bytes



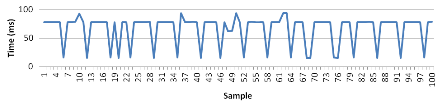
(f) 100 Bytes



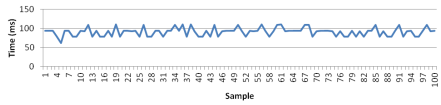
(g) 150 Bytes



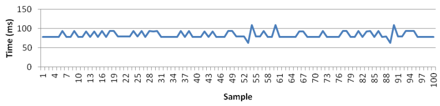
(h) 200 Bytes



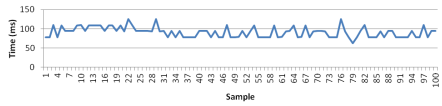
(i) 250 Bytes



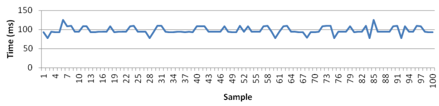
(j) 500 Bytes



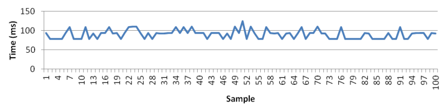
(k) 750 Bytes



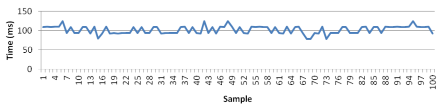
(l) 1000 Bytes



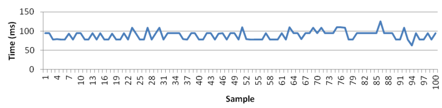
(m) 1250 Bytes



(n) 1500 Bytes



(o) 1750 Bytes



(p) 2000 Bytes

Figure 7: Transmission time for different sizes with Bluetooth 2.1 (100 samples per size).

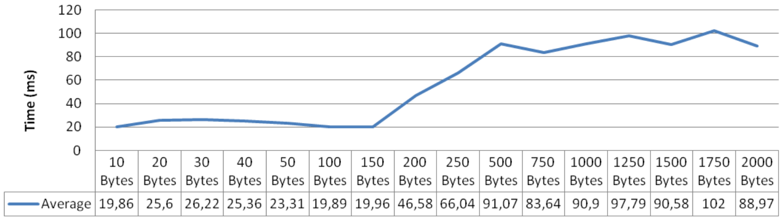


Figure 8: Evolution of the transmission time for the different sizes in Bluetooth 2.1.

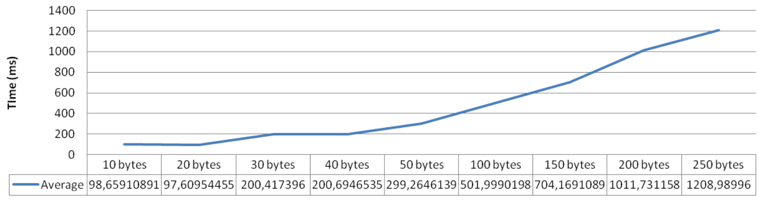


Figure 9: Evolution of the transmission time for the different sizes in Bluetooth Low Energy.

5.2 Bluetooth Low Energy

Figure 9 the evolution of the delay when the size is increasing, and the Figure 11 presents exhaustively the results for 100 tests with the platforms described defining different packet sizes.

This presents a constant time of 100 ms by request, since the duty cycle from the BLE is defined to 100 ms. Therefore, even when the time to send the reply is under 3 ms, the delay will be directly dependent in the duty cycle from the end device. It can be seen that each frame of 22 bytes require 100 ms, and the evolution of the time grows up exponentially following this pattern.

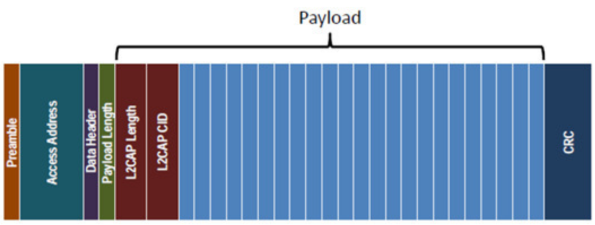
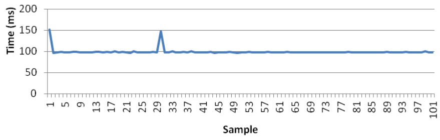
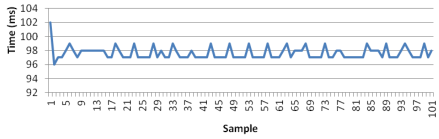


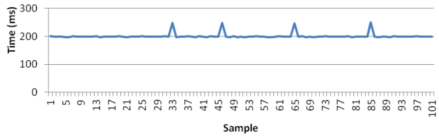
Figure 10: Bluetooth Low Energy Packet.



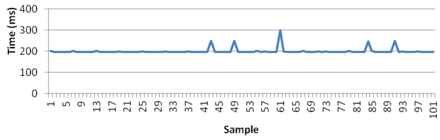
(a) 10 Bytes



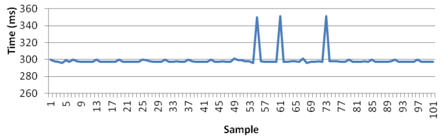
(b) 20 Bytes



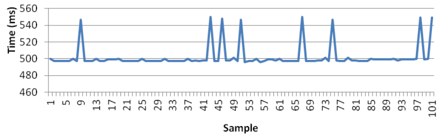
(c) 30 Bytes



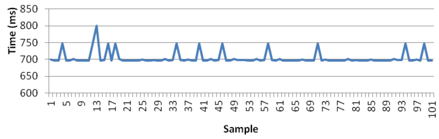
(d) 40 Bytes



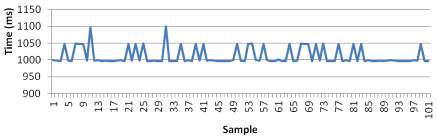
(e) 50 Bytes



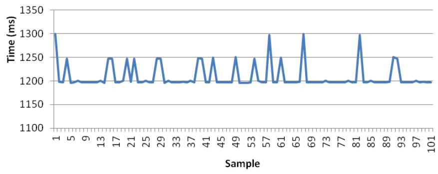
(f) 100 Bytes



(g) 150 Bytes



(h) 200 Bytes



(i) 250 Bytes

Figure 11: Transmission time for different sizes with Bluetooth Low Energy (100 samples per size).

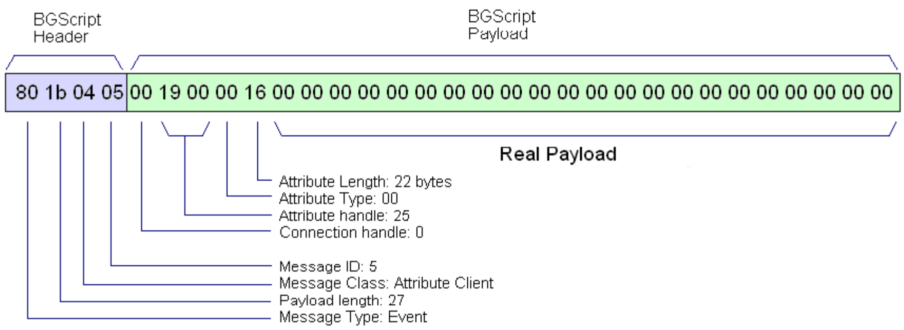


Figure 12: BGScript use of the BLE payload for non-encrypted mode (i.e. 31 bytes, 27 bytes in case of encryption).

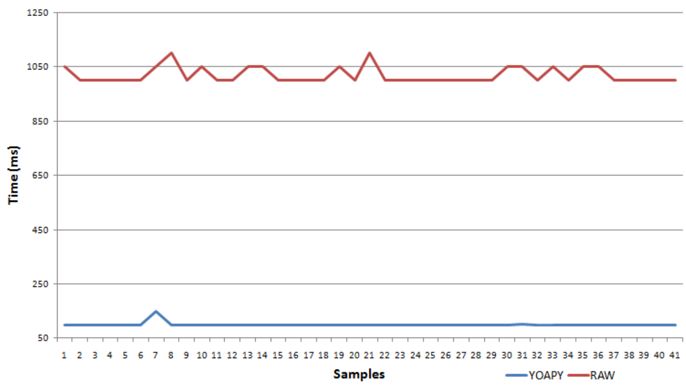


Figure 13: Time comparative between the RAW mode and the compressed transmission mode (YOAPY).

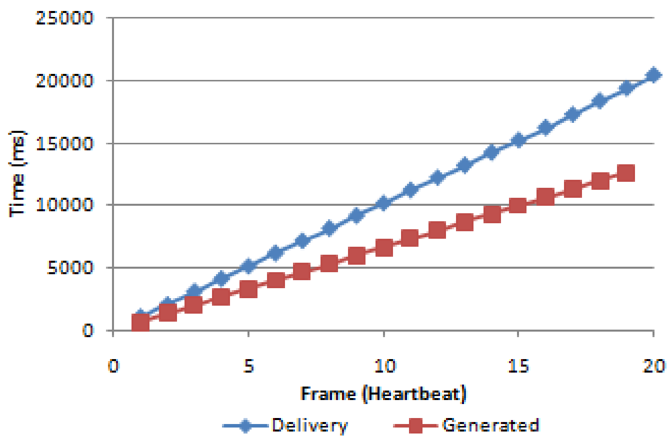


Figure 14: Cumulative delay when using RAW mode.

6 Discussion

Given the limited payload provided by BLE (31 Bytes) such as presented in the Figure 10 and in particular the 22 bytes available with the solution from Bluegiga because the reduction due to the BGscript header 12. It is not feasible to transmit data with the communication requirements of the Section 3.

For that reason, it requires a pre-processed process to make BLE transmission feasible. These pre-processing and adaptation tasks also include complex data analysis for the detection of anomalies, compression and security techniques.

An evaluation has been carried to determine the time intervals and delays to retrieve an attribute that contains the heartbeat information from the DKBLE112 to a Bluetooth enabled PC. This evaluation emulates the functionality of a smart ECG device, a device that can be fit onto the IoT concept.

It has been compared between a version of the solution based on the full wave trace transmission, i.e. a 200 bytes frame per heartbeat from RAW mode, and the YOAPY pre-processed mode of sending only 12 bytes per heartbeat.

YOAPY is an pre-processed format for continuous clinical data presented previously in [Jara et al. 2013a, Jara et al. 2013b] for 6LoWPAN and NFC.

RAW data requires to send 200 bytes per heartbeat, i.e. 10 BLE packets, since the maximum payload available per packet is 22 bytes as has been seen before. Nine of the 10 packets contain 22 bytes of payload and an additional packet with 2 bytes completes the full heartbeat information in the RAW mode.

All comparison shown below has been made with DKBLE112 powered through battery at 50 cms of distance and using the same frame size. Figure 13 shows a graph where you can see the time it takes to send frames (always containing

Table 3: Time delay measures for both vital signs transmission modes.

Measure	**RAW**	**YOAPY**
Max	1099,61 ms	149,41
Average	1013,44 ms	100,40
Min	998,04 ms	97,655 ms

the same data) in the different modes described. 40 samples were taken in order to obtain an average that approximates better the delivery time, which will be used below to perform certain calculations.

The average time measured for transmissions in RAW mode was 1013,44 ms, and 100,40 ms for the solution based on the YOAPY mode. Table 3 shows maximums and minimums for both transmission modes

It is concluded that, the RAW mode transmissions produces a delay for real-time and continuous monitoring of vital signs since its required more than 1 second for delivering a sample which is obtained in less than 1 second (90 beats per minute, means a heartbeat each 0,67 seconds). These measures permit us calculate the delay produced following the equations 2 and 3:

$$\frac{3600\ sec}{1.01344\ sec\ per\ frame} = 3552.25\ frames \tag{2}$$

$$0.67\ sec\ per\ heartbeat\ *\ 3552.25 = 2380\ seconds \tag{3}$$

Being 1.01344 seconds the average time to send a complete frame in RAW mode. Therefore, in one hour, it is sent 3553 samples. Thereby, 1518 value corresponds to the pulse generated in the instant 2380 seconds, being the heartbeat time 0.67 seconds to 90 bpm. Hence, when the patient is monitored for 1 hour, the sample displayed corresponds to 20 minutes before, i.e. it is suffered a high delay.

An example of this accumulative delay is presented in Figure 14, the red line indicates when the heartbeat has occurred and the difference with the blue, is the delay to deliver it. It is possible appreciated how the time difference grows increasingly.

Therefore, the use of RAW mode is not feasible, since it produces an accumulative delay. However, with the use of the YOAPY mode and its compression mechanisms we can send this information with a shorter delay, around 0.1 seconds, which is under the threshold of the 0.67 seconds.

To reach a better approximation, has been carried out a set of test in order to obtain measures about the process time consumed by YOAPY compression method. YOAPY needs two ECG frames, current and previous (each frame contain half heartbeat), to gather the full information for a heartbeat.

YOAPY spends around 15 ms to obtain two frames from an input buffer and process it (start the process) using the before mentioned hardware (Movital). After this initial process, when it has been already processed the previous frame, then this takes only around 1 ms read the newest frame and process it together. Therefore, this small delay produced by the pre-processing module (YOAPY) makes feasible the real-time transmission.

7 Conclusions and Future Work

Bluetooth classic presents a higher capabilities due to its higher bandwidth and frame size. From 10 to 150 bytes present a similar delay, after this the time is increased but even for 2000 bytes the time is under 100 ms, which is the time required by BLE for a single packet of 22 bytes.

BLE technology does not replace Bluetooth classic, since BLE offers a different range of functions and it is not compatible with Bluetooth Classic. For that reason, most of the Bluetooth chips are dual mode, securing a path for the rapid spread of low-energy applications, at the same time that offering support for existing applications such as voice, which will continue in the Bluetooth classic. However, emerging applications such as sensor networks and ambient intelligence solutions will communicate through BLE. Several devices are integrating nowadays dual stacks of BLE and Bluetooth classic such as smart phones, laptops and tablets.

BLE presents high constraints in aspects such as the available payload and bandwidth transmission. Therefore, it is not possible transmit the RAW data obtained directly from the ECG output through this kind of transmission technology. It has been necessary a pre-process to make feasible the transmission of vital signs in order to reach a real-time monitoring. The proposed solution reduces the overload due to the wave RAW data and provides a set of values with information about the analysis carried out during the pre-processing of the wave, which can be used for diagnosis purpose.

Future work is mainly focused on the integration of IPv6 over Bluetooth Low Energy through GLoWBAL IPv6 protocol [Jara et al. 2012] in order to give an own identifier and offer Internet access to the smart devices enabled with BLE. In addition, we are expecting the release of a new transceiver with interface to access to the L2CAP directly instead of accessing through the proprietary application protocol, such as offered by Bluegiga, in order to continue our studies about communication capabilities of the BLE stack.

Acknowledgments

This research has been conducted partially by the Intelligent Systems and Networks group of the University of Murcia, awarded for its excellence as a research group in the frames of the Spanish "Plan de Ciencia y Tecnología de la Región de Murcia" from the "Fundación Séneca" (04552/GERM/06). The authors would like to thank the European Project "Universal Integration of the IoT through an IPv6-based Service Oriented Architecture enabling heterogeneous components interoperability (IoT6)" from the FP7 with the grant agreement no: 288445, the Spanish Ministry for Industry, Tourism and Infrastructure, and the Ministry for Education, Social Politics and Sport for sponsoring the research activities under the grants "Architecture for Intelligent Respiratory Evaluation (AIRE)" (TSI-020302-2010-95) and FPU program (AP2009-3981).

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