Smartphone and Bluetooth Smart Sensor Usage in IoT Applications

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Abstract: Bluetooth Low Energy is an interesting short-range radio technology that could be used for connecting tiny devices into the Internet of Things (IoT) through gateways or cellular networks. For example, they are widely used in various contexts, from building and home automation to wearables. This paper proposes a method to improve the use of smartphones with a smart wireless sensor network acquisition system through Bluetooth Low Energy (BLE). A new BLE Smart Sensor, which acquires environmental data, was designed and calibration methods were performed.

A detailed deviation is calculated between reference sensor and sensor node. The data obtained from laboratory experiments were used to evaluate battery life of the node. An Android application for devices such as Smartphones and Tablets can be used to collect data from a smart sensor, which becomes more accurate.

Keywords: Bluetooth low energy, Internet of things, Wireless sensor networks, Smartphone applications.

1. Introduction

The general idea of the Internet of Things is to make network devices able to sense and collect data from the world around us, and then share that data across the Internet where it can be processed and utilized for various interesting purposes. For instance, instead of being controlled by human beings, sensors, actuators and appliances will work directly to measure and respond to a wide variety of data such as temperature, how much power is consumed, or body functions such as blood pressure or heart rate [1-2].

Wireless sensor networks (WSN) are a relatively new and fast developing area of IoT applications, which can provide processed real time data acquisition from sensors distributed in remote areas. The sensor nodes deployed on the specific places measure various environmental parameters. These measurements can help in making decisions on irrigation (automating, semi automating), fertilizer and pesticide applications, intruder detection, pest detection, yield prediction, plant disease prediction [3-7]. Hardware is currently an active research area carried out in universities around the world and in private companies. The possibilities in this field are endless due to the increasing demand to look for new sensors for different applications, the advances in miniaturization, components to be integrated, or new features to save energy. In this sense, WSN technology is clearly the most promising candidate to significantly improve automation systems of specific areas or places. In combination with low-cost communication modules and Bluetooth Low Energy (BLE) sensor motes, the new lower overall costs of WSN for smartphone applications are driving the possibility for more cost-effective applications than previously reported [8].

BLE is expected to appear in billions of devices and sensors in the next few years. The issue of power consumption of the remote devices is one of the main issues of today's IoT applications; therefore, in December 2009 it was introduced by the Bluetooth Special Interest Group to address this. The main feature of BLE is the Bluetooth specification v4.0. It is a new protocol which allows for long-term operation of Bluetooth devices that transmit low volumes of data. It enables smaller form factors, better power optimization, and the ability to operate on a small power cell for several years [9].

A different approach was used in [10], where several sensors used with different structures. In fact, increasing the number of distributed sensors maximizes the lifetime of the network, since more failures can be tolerated; this tackles the power consumption challenge. Another advantage of applying more sensors at the same time is an increased reliability of the network. The smartphone application manages the sampling frequency and the method of connection between sensors using an independent communication with each sensor, without the need for multi-hop routing to gather environmental information. The data is gathered and analyzed directly by the smartphone application. A new device was developed for data acquisition and improved android application [10] with the possibility of acquiring data from several sensors at the same time. However, hardware design and power consumption was far from optimal.

In this paper, the authors designed a completely new device, which has the benefits of low cost and low power consumption using BLE technology. Moreover, we developed a new android application with the ability to communicate with BLE devices (see Fig. 1).

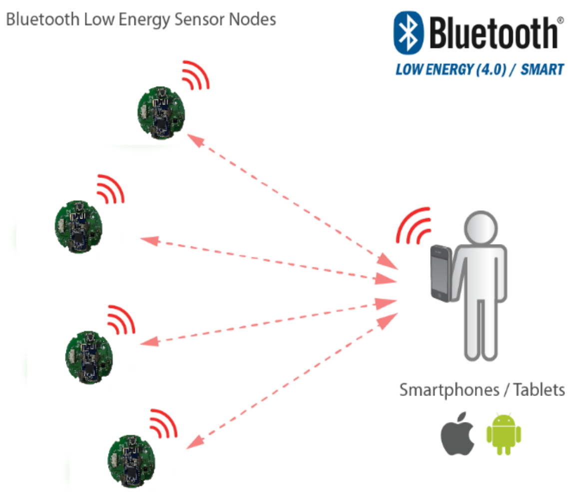


Fig. 1. BLE-based wireless sensor network to collect environmental data for smartphones.

The rest of this paper is organized as follows. Section II describes the hardware design and algorithm of the android application. In Section III we present the cover box of temperature and humidity acquisition system. Section IV discusses the future work and new ideas. We close the article with acknowledgements.

2. Methods

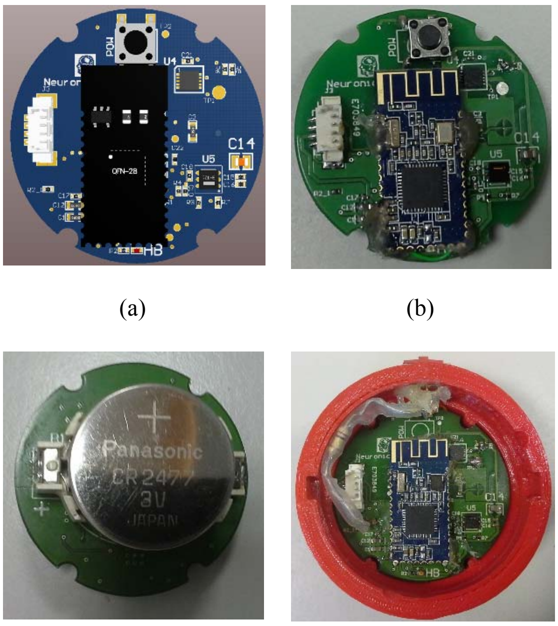
2.1. Bluetooth Low Energy Smart Sensor

The authors of [10] presented Classic Bluetooth based temperature and humidity acquisition system. They used low power components but most of the power consumption was due to the classic Bluetooth module. The power consumption of the classic Bluetooth is 26 mW while it is waiting connection and 90 mW during the transmission [10]. Concerning the power consumption of the device a new BLE based temperature and humidity device was designed.

In order to reduce power consumption on the hardware part, we used a low power temperature and humidity sensor (SHT21 from Sensirion, temperature range from -40 to +125 °C and accuracy of 0.3 °C, humidity range from 0 to 100 % and accuracy of 2 %) [21]. The I2C protocol is used to communicate between sensor and microcontroller. For this system, a MSP430G2553 microcontroller from Texas Instrument MSP430 family has been selected. It is an ultra-low-power microcontroller. The architecture, combined with five low-power modes, is optimized to achieve extended battery life in portable measurement applications. The device features a powerful 16-bit RISC CPU, 16-bit registers, and constant generators that contribute to maximum code efficiency. The digitally controlled oscillator (DCO) allows wake-up from low-power modes to active mode in less than 1 µs. In addition, it has a 10-bit analog-to-digital (A/D) converter. In order to avoid power consumption, the microcontroller switches on the temperature and humidity sensor only during the acquisition of the environmental parameters; after this it switches for 15 seconds off. In addition, the microcontroller puts itself in a low power mode between two consecutive measurements in order to save power. The reasons for choosing BLE are that it consumes less power and costs less compared to the Classic Bluetooth. In addition, its simplicity, wide range of users, the capability to work in the absence of WiFi and, most importantly, the fact that the new models of smartphones support BLE [11-13] are very important factors.

The BLE module HM-10 from JNHuaMao Technology Company was used to design the device. It is compatible with the new standard Bluetooth 4.0. BLE is a new short range radio technology, optimized for ultra-low power applications. It is different from Bluetooth classic (BR/EDR), but with same benefits like robustness, interoperability, royalty free or connectivity with smartphones and PCs. BLE module consumes 0.01 to 0.5 W while transmitting. The BLE module receives data from the Universal

Asynchronous Receiver/Transmitter (UART) interface of the microcontroller, and forwards it to a receiver using the Generic Access Profile (GAP). GAP is the cornerstone that allows Bluetooth Low Energy devices to interoperate with each other. It provides a framework that any BLE implementation must follow to allow devices to discover each other, broadcast data, establish secure connections, and perform many other fundamental operations in a standard, universally understood manner. There is a button on the device which switches the BLE module on only during transmission of the data and turns it off after transmission. In [1] the authors used a 3 V lithium coin battery (Energizer CR2032), but in order to increase the life of the sensor node we used a 3 V lithium-manganese dioxide coin battery CR2477 with a minimum capacitance of 1000 mA. Fig. 2 shows the 3D version, final prototype board of the BLE-based temperature and humidity acquisition system, which is located inside the box.



(a) (b) (c) (d)

Fig. 2. (a) 3D version of the electronic circuit BLE-based temperature and humidity acquisition system; (b) Prototype board: Top view temperature and humidity sensor, microcontroller and BLE module; (c) Bottom view of the device; (d) Top view of prototype board with a CR2477 Panasonic battery inside plastic box.

2.2. Android Application of Bluetooth Low Energy Smart Sensor

An android application for the BLESensor was developed on an updated version of Android Studio.

BLE communication settings and algorithms are implemented in application. The software model of BLE is described below:

2.2.1. Client

A device that initiates Generic Attribute Profile (GATT) commands and requests, and accepts responses, for example a computer or smartphone.

2.2.2. Server

A device that receives GATT commands and requests, and returns responses, for example a temperature sensor.

2.2.3. Characteristic

A data value transferred between client and server, for example the current battery voltage.

2.2.4. Service

A collection of related characteristics, which operate together to perform a particular function. For instance, the temperature and humidity acquisition services include characteristics for a temperature measurement value, and a time interval between measurements.

2.2.5. Descriptor

A descriptor provides additional information about a characteristic. For instance, a temperature value characteristic may have an indication of its units (e.g., Celsius), and the maximum and minimum values which the sensor can measure. Descriptors are optional - each characteristic can have any number of descriptors.

Some service and characteristic values are used for administrative purposes - for instance, the model name and serial number can be read as standard characteristics within the Generic Access service. Services may also include other services as sub-functions; the main functions of the device are so-called primary services, and the auxiliary functions they refer to are secondary services.

2.2.6. Identifiers

Services, characteristics, and descriptors are collectively referred to as attributes, and identified by UUIDs. Any implementer may pick a random or pseudorandom UUID for proprietary uses, but the Bluetooth SIG have reserved a range of UUIDs (of the form xxxxxxxx-0000-1000-8000-00805F9B34FB [11]) for standard attributes. For efficiency, these identifiers are represented as 16-bit or 32-bit values in the protocol, rather than the 128 bits required for a full UUID. For example, the Device Information service has the short code 0x180A, rather than 0000180A-1000-.... The full list is kept in the Bluetooth Assigned Numbers document online.

2.3. Interfaces

In this section all the screens of the application will be described. The BLESensor application consists of three screens: main screen, home screen (digital and analog interfaces) with switch button and .xml extension file where we store our data.

2.3.1. Main Screen

The main screen illustrated in Fig. 3 allows the user scan BLE devices to connect to the BLESensor node, and set a sampling time.

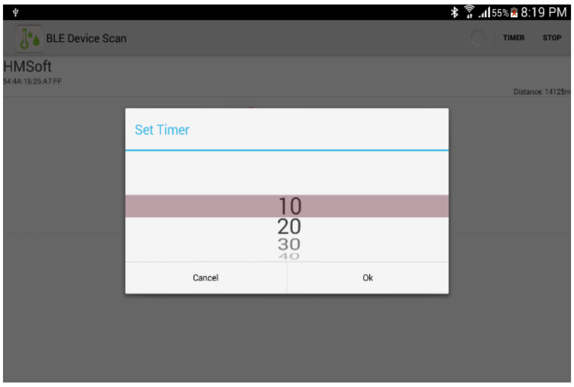


Fig. 3. Timer setting screen of the android application.

2.3.2. Home Screen

The home screen consists of two digital and analog interfaces, which are shown, in Fig. 4 and Fig. 5. The switch button on the screen allows the user to switch from one to another screen. In this screen, the user can see the acquired temperature and humidity values of an exact place. All the data, which is acquired from the sensor node, saves as .xml extension file and stores in the memory of the smartphone. It can also be sent by e-mail or store in servers. Furthermore, we use these data to calibrate our sensor.

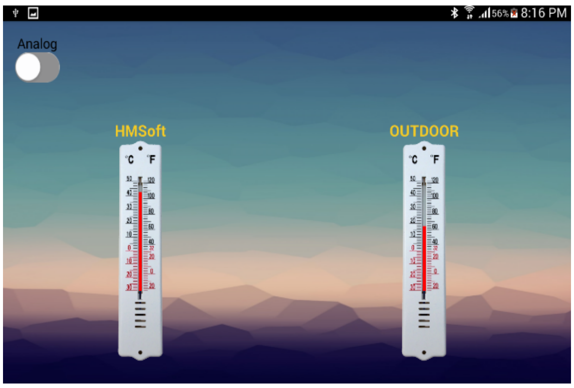


Fig. 4. Analog interface of the android application.

Fig. 5. Digital interface of the android application.

2.4. Implementation and Algorithm of the BLESensor

The Algorithm of the application: BluetoothLeService class provides a service for managing connection and data communication with a GATT server hosted on a given BLE device. DeviceControlActivity class checks whether there is Bluetooth LE communication or not and if yes display data. Moreover, this activity provides GATT services and characteristics supported by the device. The software continuously checks for the availability of the sensor and after communication it remembers the last connection [13].

The BLESensor application has a menu for discovering and selecting the desired BLE-based sensor to get characteristics. This part of the application is called Discover UUIDs, and, for all primary services, after running the application, it tries to find service with a given UUID. The software discovers all characteristics for a given service. The next step is to find a characteristic matching with a given UUID where after application reads all descriptors for particular characteristics.

Finally, GATT offers notifications and indications. The client may request a notification for a particular characteristic from the server. The server can then send the value to the client whenever it becomes available. For instance, a sensor (SHT21) server may notify its client every time it takes a measurement. This avoids the need for the client to poll the server, which would require the server's radio circuitry to be constantly operational.

An indication is similar to a notification, except that it requires a response from the client, as confirmation that it has received the message.

The next part of the application is called discovery. BLESensor can distinguish between a Bluetooth classic based device and a BLE-based device. Sensors will be saved as Pair-Sensors after each communication. After selecting sensor/s, the process of connecting starts. In some cases, two attempts are needed to connect to the sensor. If the standard method of connecting fails, the reflection method starts.

The obtained data stream needs to follow the process of tokenization to break desired values of temperature and humidity from several lines of data that are read from the sensor [11]. Acquired data is computed with the formula of the SHT21 sensor from the datasheet. Additionally, all sensor data is stored in a text file in the data storage of the mobile phone. The application has a setting to select the number of available sensors to follow and the mentioned processes will happen automatically. The main interface of the BLESensor application is shown in Fig. 6. It illustrates how two sensors send indoor and outdoor environmental data to the BLESensor mobile application.

Fig. 6. Main Interface of the BLE-based android application for acquiring environmental data.

3. Cover Box for Temperature and Humidity Device

The development of low-cost desktop versions of three-dimensional (3D) printers has made these devices widely accessible for rapid prototyping and small-scale manufacturing in home and office settings [15]. For this project, the Sharebot NG 3D printer available in the Neuronica Lab was used. 3D printing is a process of making three-dimensional solid objects from a digital file. The creation of a 3D printed object is achieved using additive processes.

In an additive process, an object is created by laying down successive layers of material until the entire object is created. Each of these layers can be seen as a thinly sliced horizontal cross-section of the eventual object [16].

The design started by making a virtual design of the object using SOLIDWORKS 2015 x64 Edition and used STL file to print in 3D printer [17].

Another issue of the device was protection from environmental impacts. Moreover, esthetically it requires being attractive and easy to use for users. For that reason, we designed a cover box for the device. The size of cover box is reduced as much as possible [17]. 3D dimension of the cover box is provided in Fig. 7.

4. Experiments

This section describes the obtained results of manufacturing, assembling and calibration.

(A) (B)

Fig. 7. (A) Final printed product with sensor inside with a switch (B) First printed product with sensor inside with a button.

4.1. Experiments and Results

The sensor was characterized by comparing repeated measurements with Testo735 but we used a platinum resistance thermometer for calibration. The BLESensor and reference sensor were inserted in the climatic chamber of the Neuronica Lab (Angelantoni – Challenge 250) which has a temperature range for climatic testing from -40 °C to +180 °C. The Experimental works at the laboratory with chamber is illustrated in Fig. 8.

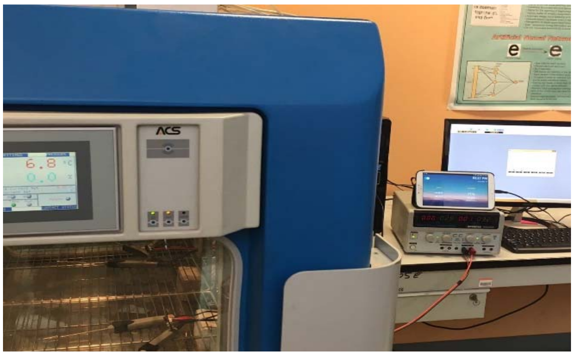


Fig. 8. Experimental works with Angelantoni – Challenge 250.

The relation between the resistance and the temperature of platinum resistance thermometers (RTD) is described by the Callendar-Van Dusen equation:

$$R(t) = R_0 \cdot \left[1 + A \cdot t + B \cdot t^2 + C \cdot (t - 100) \cdot t^3\right], \quad (1)$$

where R_0 is the resistance of 100 Ohms at 0 °C, R(t) is the resistance in function of the temperature t, while the coefficient A, B and C are given by the IEC751 standard:

$$A = 3.9083 \cdot 10^{-3} \text{ °C}^{-1}$$

$$B = -5.775 \cdot 10^{-7} \text{ °C}^{-2}$$

$$C = -4.183 \cdot 10^{-12} \text{ °C}^{-4}$$

The following procedures were carried out to characterize the chamber: Initially the climatic chamber was set to a temperature of 40 ^{o}C and held about 5 minutes. Every two minutes the temperature was decreased by 1 ºC up to -10 ºC. When the temperature reached -10ºC this temperature was kept about 5 minutes and after the temperature was increased again up to 40 ºC in steps of 2 ºC per minute (see Fig. 9).

The results, were plotted in a graph using Matlab, and the deviation was estimated.

Fig. 9 illustrates the measurements, which are taken without any plastic box, while Fig. 10 shows the sample obtained using the BLESensor node contained in the plastic box. The experimental results show that the node behaves in a good manner. Furthermore, the plastic box gives an offset error of 1.2°C that can be directly compensated by software. Comparing each sample of the measurements, after adding the offset by software, it is possible to calculate the maximum, minimum and average deviation.

Maximum deviation = 1.5 °C;
Minimum deviation = 0.4 °C;
Average deviation = 0.6969 °C;

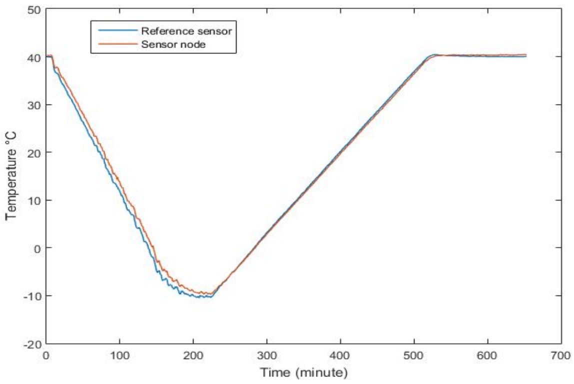


Fig. 9. Measurement results from reference sensor and sensor node without plastic box.

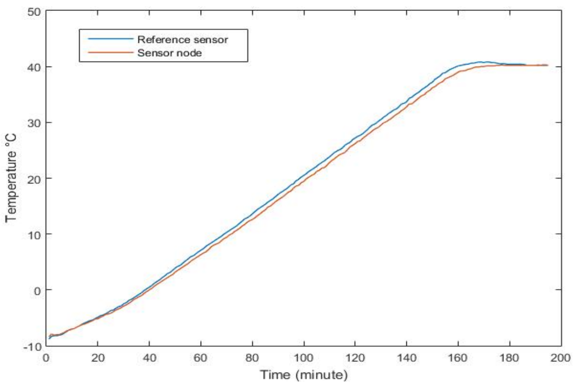


Fig. 10. Measurement results from reference sensor and sensor node with plastic box.

5. Power Consumption

The power consumption of the BLESensor was measured with Tektronix MDO3104 oscilloscope. All the contributes of power are well known thanks to the data sheet, so it is possible to make a rough estimation.

The measurements at the oscilloscope allows the checking and evaluation of the duty cycle of the sensor node. In fact, the sampling time was set from the android application.

Fig. 11 describes all the measurements from the oscilloscope. In this acquisition the android application is set for 10 seconds of sampling time.

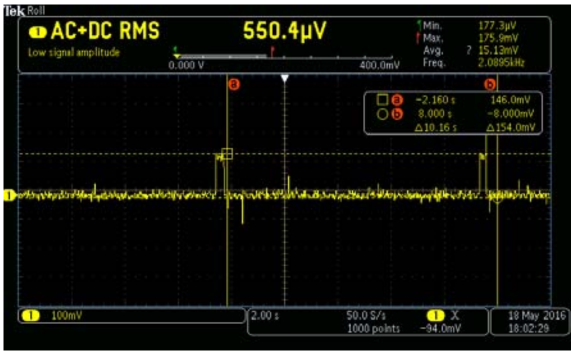


Fig. 11. BLESensor measurements during sampling process.

The first peak current comes from the transmission phase: the duration of this current is so small that it can be neglected. From the illustration we can take some important parameters for further calculation of the battery life of BLESensor node. During the measurement, we used 10 Ohm resistor. The values from Fig. 11 allow us to calculate the current consumption from the Ohm's Law:

$$I = V / R = 175.9mV / 10 = 17.59mA \quad (2)$$

The obtained value is reasonable since the current consumption of the transceiver during receiving is equal to 15 mA. The additional value is due to all the other IC's current consumption. The transmission time is 50.4 ms. This value is important to derive the node lifetime, which will be discussed in the next section. Table 1 shows all the power consumption of components in sleep mode and wake up mode. These values allow us to make better calculation of the power peak current.

Table 1. Power consumption of the active components.

Name of the components	Sleep mode	Wake up mode
MSP430G2553	0.5 µA	420 µA
SHT21	-	330 µA
HM-10 Bluetooth module	600 µA	15 mA

From the table it is clear that the system consumes 600.5 µA during the sleep mode and 15.75 mA in the wake up mode. Other current consumption might occur during wake up, due to light-emitting diodes (LED) or leakages.

5.1. BLESensor Lifetime

In order to evaluate the battery lifetime, the average value of the current must be used. This can be calculated from the duty cycle, so the battery life is:

$$BatteryLif\ e = Capacity\ \cdot \frac{T_{on} + T_{off}}{I_{\max} \cdot T_{on} + I_{\min} \cdot T_{off}} \quad (3)$$

Taking into account the parameters, which is taken from the measurements and datasheets I_{max}=17.59 mA, I_{min} = 600.5 μA, T_{on} = 40 ms and assuming a sampling time of 10 min, the battery life time can be computed from a second equation:

$$BatteryLife = \frac{10{\cdot}60s}{17.59mA{\cdot}40ms{+}0.6mA{\cdot}10{\cdot}60s} \cdot 1000mA = 565hours$$

Therefore, considering a sampling time 10 minutes the BLESensor node lifetime is about 4 weeks. The chosen sampling time is reasonable for green house and home automation applications where temperature and humidity change slowly. Moreover, we can change a sampling time from the android application.

6. Conclusions

This paper introduces a device designed with low power components, which acquires environmental data through BLE technology and sends it to an android application developed on Android Studio. Further obtained data, which is in .xml extension and XML data format can be sent via e-mail for analyzing data. In this use case portable devices are used to send data to the Internet as the part of IoT application. [14].

Experiments using a climate chamber with various environmental conditions, allowed us to determine the accuracy of the sensor node. At the same time, we tested the power consumption of the device during each condition to determine if the changes in environmental conditions alter the power consumption in any way. The obtained data were used to calculate the battery life of the sensor node. The amount of power, which was consumed, was only theorized in the previous paper [1]. At this point, physical data which coincide with this theorem confirmed our original hypothesized consumption levels.

The next area of our work will focus on Network topology for BLE. This is an area of interest because billions of sensors and actuators will be deployed in the next few years and an emerging trend is to connect sensors with Internet of Things (IoT). The low-power radio technology has perhaps the highest potential for IoT use. The application which is still lacking IP capability is BLE which is expected to be incorporated in billions of consumer electronic devices around the globe (e.g., smartphones, tablets, Google glass, etc.,) [19]. Accordingly, the capability to run IPv6 over BLE opens new doors to the IoT and promotes BLE towards new application areas. The most important of these areas would be to exploit the smartphone as a gateway for providing Internet connectivity to surrounding BLE-enabled sensors. For instance, this approach allows one to remotely and ubiquitously monitor medical parameters from body sensors. Another example of the use of this application is with vehicle health messages, which can be sent by vehicular sensors through the smartphone of the driver to remote Intelligent Transportation System (ITS) control centers in order to prevent accidents. Similar applications can be found in other domains including home, urban and industrial automation. Furthermore, enabling IPv6 over BLE contributes to interoperability between IoT devices that utilize different low-power radio technologies. This is particularly important since Internet Engineering Task Force (IETF) standardization work is currently progressing towards extending the family of low-power technologies with IPv6 support [18]. Other experiments have been proposed with the goal of implementing different learning machine tools in Wireless Sensor Networks in order to predict a sensor data will also be investigated. In conclusion, the use of BLE technology with our Android system can reduce power consumption on the whole system [19].

Acknowledgements

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References

[1]. Kh. Aliev, F. Rugiano, E Pasero, The Use of Bluetooth Low Energy Smart Sensor for Mobile Devices Yields an Efficient Level of Power Consumption, in *Proceedings of the 1st International Conference on Advances in Sensors, Actuators, Metering and Sensing (ALLSENSORS'16)*, Venice, Italy, 24-28 April 2016, pp. 5-9.

[2]. A. Zeeshan, Y. Wonyong, A Survey on Energy Conserving Mechanisms for the Internet of Things: Wireless Networking Aspects, *Sensors*, Vol. 15, Issue 10, 2015, pp. 24818-24847.

[3]. A. Zanella, N. Bui, A. Castellani, Internet of Things for Smart Cities, *IEEE Int. Things J.*, Vol. 1, Issue 1, 2014, pp. 22-32.

[4]. S. Yoo, J. Kim, T. Kim, S. Ahn, J. Sung, D. Kim, A^2S Automated Agriculture System Based on WSN, in *Proceedings of the IEEE International Symposium on Consumer Electronics (ISCE'07)*, Irving, TX, USA, 2007, pp. 1-5.

[5]. S. K. Kurmi, R. Verma, A. K. Sharma, Modern Organic Precision E-Agriculture (MOPEA) Using Energy Efficient Wireless Sensor Network (WSN) Technology, *International Journal of Emerging Technology and Advanced Engineering*, Vol. 3, Issue 5, 2013, pp. 663-667.

[6]. M. Keshtgari, A. Deljoo, A Wireless Sensor Network Solution for Precision Agriculture Based on Zigbee Technology, *Wireless Sensor Network*, Vol. 4, No. 1, 2012, pp. 25-30.

[7]. K. GopalaKrishna Moorthy, C. Yashuwanth, K. Venkatesh, A Wireless Remote Monitoring of Agriculture Using Zigbee, *International Journal of Engineering and Innovative Technology (IJEIT)*, Vol. 2, Issue 8, 2013, pp. 72-74.

[8]. Adam Dunkels, Programming Memory-Constrained Networked Embedded Systems, PhD Thesis, *Mälardalen University,* 2007.

[9]. Android developer web portal (http://developer.android.com/index.html).

[10]. S. Aram, A. Troiano, E. Pasero, Environment sensing using smartphone, in *Proceedings of the IEEE Sensors Applications Symposium (SAS),* Brescia, 2012, pp. 1-4.

[11]. S. Aram, A. Troiano, F. Rugiano, E. Pasero, Low Power and Bluetooth-Based Wireless Sensor Network for Environmental Sensing Using Smartphones, in Artificial Intelligence Applications and Innovations, *IFIP Advances in Information and Communication Technology*, Vol. 382, 2012, pp. 332-340.

[12]. Bluetooth developer portal: (https://developer.bluetooth.org/Pages/default.aspx).

[13]. Safari books online. (https://www.safaribooksonline.com/library/view/getting-started-with/9781491900550/ch01.html).

[14]. Android developers portal: (http://developer.android.com/develop/index.html).

[15] Stephens Brent, *et al.*, Ultrafine particle emissions from desktop 3D printers, *Atmospheric Environment,* Vol. 79, 2013, pp. 334-339.

[16] Szokolay Steven V., Introduction to architectural science: the basis of sustainable design, *Routledge*, 2014.

[17]. Dassault Systemes SolidWorks Corporation. (http://www.solidworks.com/

[18]. IPv6 over Networks of Resource-Constrained Nodes (6lo). Proposed Working Group charter, 2013, http://datatracker.ietf.org/wg/6lo/charter/

[19]. J. Nieminen, C. Gomez, M. Isomaki, T. Savolainen, B. Patil, Z. Shelby, M. Xi, J. Oller, Networking Solutions for Connecting Bluetooth Low Energy Enabled Machines to the Internet of Things, *IEEE Network Magazine*, Vol. 28, Issue 6, 2014, pp. 83-90.

[20]. Sensirioin The Sensor Company. https://www.sensirion.com/products/digital-humidity-sensors-for-reliable-measurements/humidity-temperature-sensor-sht2x-digital-i2c-accurate/
