Reducing Power Consumption in Smart Monitoring Systems with BLE Wireless Technology

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Abstract. This research focuses on alternative low power consumption in smart monitoring systems and on various techniques to facilitate access to different monitoring sensors connected via Bluetooth Low Energy (BLE). Due to high complexity and power demands that new smart monitoring equipment have, the need for reduced power consumption in the context of new regulations/architectures for the Internet of Things has occurred. Sensors can have dimensions of a few centimeters, are not required to have cabling or power supply and can transmit data for a long period of time. A network of sensors connected through BLE wireless technology with a corresponding architecture can provide a simple and versatile solution to multiple environments that need to be monitored. Data provided by the smart monitoring systems must be carried and analyzed either in upper layers of the network or close to the edge. Dedicated applications allow users to access data via smart-devices and data can be downloaded on any device, such as mobile phones. All these require communication technologies with optimized and reduced power consumption, also increasing battery lifetime and becoming more eco-friendly.

1. Introduction

As the world population rapidly increases, inversely proportional the resources of the planet also continue to fast diminishing, therefore more and more researchers become concerned about the waste management, as well as recycling. In an era dominated by computers, technology and artificial intelligence one can refer to waste in the form of energy consumption, limited data storage, raw processing power and so on, the need to reduce consumption turning into one of the main actual challenges.

Among the factors that might lead to this type of resources waste can be the diversity of existing regulations, rules or standards that define the modern equipment used in either households or in enterprise environment. Potential solution to such problems can be achieved by interconnecting all this equipment with commodity sensors, measuring set-up and embedded systems throughout machine learning techniques. This can generate a reliable communication between connected devices and all the real-time analytics that is being generated, thus creating a global connected network of connected networks also known as the Internet of Things (IoT) [1].

As mainstream IoT has become part of daily life, the need to store and process all this ever-increasing number of raw data (also known as Big Data) has been strongly accelerating in the last decade. International Data Corporation (IDC) has estimated that the total load generated by all IoT
connected devices and users, from business to healthcare, will be reaching 175 Zettabytes of data by the year 2025, compared to only 33 Zettabytes of data in 2018 and 10 times the data generated in 2016 [2]. Wireless sensor networks (WSN) has proved to be a reliable way of real time data acquisition from a group of spatially dispersed and dedicated sensors for monitoring and recording the physical conditions of the environment and organizing the collected data at a central location. WSNs measure environmental conditions like temperature, sound, pollution levels, humidity, wind, and so on and can help in taking autonomous decision making in various applications ranging from agricultural related activities (i.e. automating irrigation, fertilizer or pesticide spreading) [3, 4] to controlling and maintaining a constant temperature and humidity in strict environments such as museums and art galleries [5]. In combination with low-cost and power efficient communication modules that can be controlled and connected via Bluetooth Low Energy (BLE), WSNs may be the answer to the challenge to further reduce the power demands in smart monitoring systems, allowing scalability and extending life time in battery powered devices, as well as reducing the overall environmental impact.

2. Analysis of Bluetooth Low Energy power consumption

With the accelerated and ongoing switching to the Internet of Things, where all devices are constantly collecting and exchanging data from edge to the cloud, Bluetooth Low Energy (BLE) represents a convenient way of communication between network nodes which are wirelessly transmitting data in any given WSN [6]. The sensors can transmit data to a BLE-enabled device that is responsible for processing information, analyze it and make decisions close to the edge if necessary (e.g. life support systems or any other systems that require immediate response in case of emergency). Also, some of the data may be forwarded up-network for additional analysis and eventually storage. The BLE system can operate in low-power mode, where most of the time sensors are in a low-power state with reduced power consumption (e.g. during deep sleep mode the current consumption can be reduced as low as 1.3 – 1.4 µA), making this solution energy efficient and suitable for complete systems with strict power requirements (constrained devices). However, a BLE system can distinguish five power modes: active, sleep, deep sleep, hibernate and stop, power consumption varying depending on the mode. A lot of technologies used in IoT, such as BLE or Zigbee, have an activity cycle in which the sleep mode power consumption dominates the overall current drawn by the System on Chip (SoC). A usual power consumption in the 5 modes in a Programmable System on Chip (PSoC) produced by Cypress Semiconductor [7] is presented in Table 1.

| Power Mode          | Active     | Sleep      | DeepSleep | Hibernate | Stop       |
|---------------------|------------|------------|-----------|-----------|------------|
|                     | 1.3 mA to 14 mA | 1.0 mA to 3 mA | 1.3 µA to 15 µA | 150 nA to 1 µA | 20 nA to 80 nA |

An in depth analysis of the power consumption of Bluetooth Low Energy, ZigBee and ANT Sensor Nodes in a Cyclic Sleep Scenario and the experimental results has been done in [8], proving that BLE is a better choice for diminishing power consumption and extending battery duty cycle (Table 2).

|                     | BLE        | Zigbee     | ANT       |
|---------------------|------------|------------|-----------|
| Sleep current       | 0.78 µA    | 4.18 µA    | 3.1 µA    |
| Awake current       | 4.5 mA     | 9.3 mA     | 2.9 mA    |
| Min current (at 120 sec interval) | 10.1 µA | 15.7 µA | 28.2 µA |
Another study [9] pointed out the impact of sleep current consumption on an application powered by a coin-cell battery which might be in active mode 1 minute per day (0.07% active, 99.93% in sleep mode – as could be the case in a museum) comparing BLE and Wi-Fi.

**Table 3. Impact of sleep current consumption on an application powered by a coin-cell battery which might be in active mode 1 minute per day [9].**

|                | Active current | Sleep current | Average current | 225 mAh coin cell battery autonomy |
|----------------|----------------|---------------|-----------------|-----------------------------------|
| **WiFi SoC**   | 100 mA         | 1 μA          | 80 μA           | 117 days                          |
|                | 0.2 μA         | 70.2 μA       | 133 days        |
|                | 10 μA          | 14.9 μA       | 629 days        |
| **BLE SoC**    | 7 mA           | 1 μA          | 5.9 μA          | 1588 days                         |
|                | 0.2 μA         | 5.1 μA        | 1838 days       |

As seen in Table 3, the duty cycle of a battery lasts for several years due to low power consumption when using Bluetooth Low Energy.

3. **Analysis of system architectures and impact on power consumption**

A smart monitoring solution for a museum [10] was analyzed considering a low-power BLE in order to achieve the power constrains required by the network of sensors in such an environment. Considering that in spaces such as museums, internet connections and a stable power source may be limited, the proposed solution involved that several nodes are responsible for monitoring quantities of interest in different sites.

These nodes must have small dimensions and are to be powered by a small size battery, using a low power low range wireless connection in order to send the collected data. Due to their small size (usually lower than 3 cm in diameter), the sensors may be easily mounted, however this reduction in size may also become challenging when it comes to wirelessly transmit data. Although this small-size battery may bring some important challenges (e.g. limited capacity, low voltage, required power output, weight, size, shape), a short-range wireless connection between nodes may be achieved to distances up to 10 m, providing an average life expectancy of a few years without battery replacement.

Depending of their complexity, some edge nodes can partially store information in a local memory buffer, increasing the reliability of the system if an error occurs in the radio transmission.

**Figure 1.** Simplified measuring solution for a site with no Internet access and power source (worst case scenario) [10].
In the worst-case scenario presented in Figure 1, the monitoring system relies only on the internal memory of the transmitting nodes to manage collected data. Depending on capacity, power constrains or specific user needs, a given amount of data is stored locally to be later transferred via USB or other portable receiving devices whose role is to make the data available to users and larger storage facilities in the cloud.

In the scenario presented in Figure 2, the sensors (measuring nodes in the network) are constantly sending data via cabling (not always possible and not always desired due to esthetic reasons) or via a Wi-Fi connection to a powered receiver, in real time.

If a problem with the power distribution or with the Internet link arises, the data still may be collected and stored locally for a limited period of time, until the connection is re-established. This requires an additional battery for back-up, with limited capabilities depending on the power consumption, the range of transmission and frequency of reporting. A lower power consumption increases the service period for back-up if the problem with the main power-supply persists.

The architecture of the monitoring system proposed in [10] is a button architecture designed starting from the measurement sensor, which is responsible for collecting the museum environmental data, an important issue in artifact and exhibit conservation.

Based on user’s specific needs, sensors are connected to a controller and wireless transmitter equipped with an antenna using a non-volatile serial memory capable of locally storing data, the measuring node being powered with a Lithium battery (Figure 3). Therefore, power consumption at all parts becomes a critical aspect which needs to be addressed, impacting on size, lifetime and performance of the system.
In the end, the collected data is available to the user who can access the network-based storage depicted in Figure 4 using a PC or a smartphone in order to process, eventually store all the accumulated data.

Another example of the advantages of WSN is represented in [11], where sensors are used in order to provide constant measurements of humidity without impacting the esthetics of the room. In this case due to the spherical layout of the room the sensors were placed circularly, which made battery-powered nodes the valid choice.

![Figure 4. Architecture of a monitoring system [10].](image)

Considering the small dimensions of the sensors and their light weight they can be mounted everywhere with ease and provide accurate measurements throughout an increased life cycle, if power consumption is optimized and diminished per system using BLE. Another important issue concerning the measurements values that were collected during an entire year was revealed, that in the museum room the variation of humidity is greatly varying during every season. By efficiently controlling of the air conditioner, the dehumidifier and even the central heating of the room in order to maintain constant room humidity, not only the preservation of the museum exhibits was achieved, but also an optimal energy consumption in the room which decreased overall costs and helped the battery life additionally increase, due to small temperature variations.

4. Conclusions
This article presents some of the benefits of using Bluetooth Low Energy (BLE) combined with wireless sensor networks as a feasible alternative to lower power consumption, increase coverage and preserve accuracy of data collected in different environments with or without a stable Internet connection. It is estimated that a rapid increase in wireless sensor networks (WSNs) that might benefit from this technology, considering the accelerated development in the Internet of Things. Equipment in wider areas will be inter-connected and could be capable of working in scenarios in which the lack of a power source and a reliable internet connection could pose a problem. Not only the power consumption of the measurement nodes in a WSN by using BLE is optimized and minimized, but also
the overall slow variable environmental conditions also helped in preserving battery life and decrease consumption for low range low power devices. Another important result would be the fact that extending the duty-cycle of batteries, the number of batteries that need disposal would be small, thus the whole process becomes more eco-friendly.

5. References
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