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Proceeding Paper

Design, Implementation and Validation of a Bluetooth 5 Real-Time Monitoring System for Large Indoor Environments †

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Abstract: The progress of LPWAN technologies in recent years has increased their use in various types of environments as well as increased the applications in which they are used. However, due to the duty cycle limitations of license-free based technologies, they have a considerable limitation for applications with frequent data transmission or real-time data. In this regard, technologies working in the 2.4 GHz band are a compelling option to consider but their main problem concerns their limited range. Fortunately, the new Bluetooth 5 standard has a new feature (Long Range mode) that is especially useful in long distance or large indoor environments. This paper describes a practical study on this new technology for indoor environments. The performed experiments evaluate reception range, communications quality, channel occupancy, response times, and power consumption. The obtained results indicate that a three-floor building of more than 4200 m^2 may be covered with a stable signal with only two Bluetooth 5 nodes.

Keywords: Bluetooth 5; LPWAN; IoT; LE coded; real-time monitoring

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1. Introduction

LPWAN technologies have undergone constant evolution in the last years and have become widespread in many environments. However, they do have limitations in certain types of applications, one of which concerns the restrictions on transmission due to the duty cycle. In this aspect, 2.4 GHz license-exempt ISM-band technologies are the main alternative. However, such a band has worse propagation than sub-1 GHz bands and a high occupancy in many environments, thus it is normally used only for certain IoT scenarios. There are 2.4 GHz technologies like Bluetooth that have proven to provide a good data transfer power consumption ratio, while others based on the IEEE 802.15.4 standard (e.g., XBee, Thread, and ANT) offer a better sensitivity [1].

Commonly, Bluetooth is used for scenarios that require short-range communications, but with the arrival of the new Bluetooth 5 standard, studies have shown that it has improved consumption and response time [2], as well as an improved range. This is achieved thanks to a new long-range mode (LE-coded PHY) that allows for adding extra sensitivity, with respect to the legacy version of the Bluetooth 4.x standard, by lowering the data rate to 125 Kbps, which makes it a rival of IEEE 802.15.4 standard technologies in terms of range; for this reason, it is compelling for indoor use considering the additional range [3]. This new feature not only improves the communications range but also makes it more stable in environments with electromagnetic interference.

2. Materials and Methods

In order to test the performance of the Bluetooth 5 in realistic indoor scenarios, two Nordic Semiconductor development kits were used (nRF52840-DK [4]), which can transmit at a maximum power of 8 dBm and have a sensitivity of −103 dBm in the LE-coded mode.

The tests were carried out in the Scientific Area Building of the University of A Coruña (Spain), which occupies an area of roughly 4200 m^2 and is divided into three 1400 m^2 floors.

For the deployed architecture, the following considerations were taken into account. On the one hand, as one of the advantages of the system is unrestricted transmission, we decided to test the system with fast transmissions in order to estimate its performance for real-time applications. On the other hand, although Bluetooth has several topologies, we decided to use a star topology with nodes operating in the long-range mode and at maximum power, with the aim of using the smallest number of nodes to cover the largest distances as possible.

Considering the mentioned experimental setup, we decided to implement two different devices: a GATT peripheral and a GATT central that make use of the LE-coded PHY. The GATT peripheral node was located in a fixed position, updating a predefined characteristic value every 500 ms. The GATT central node was placed at different positions and, after connecting to the peripheral, read its characteristic and stored the collected information for later analysis. The positions and orientations of the deployed nodes are shown in Figure 1.

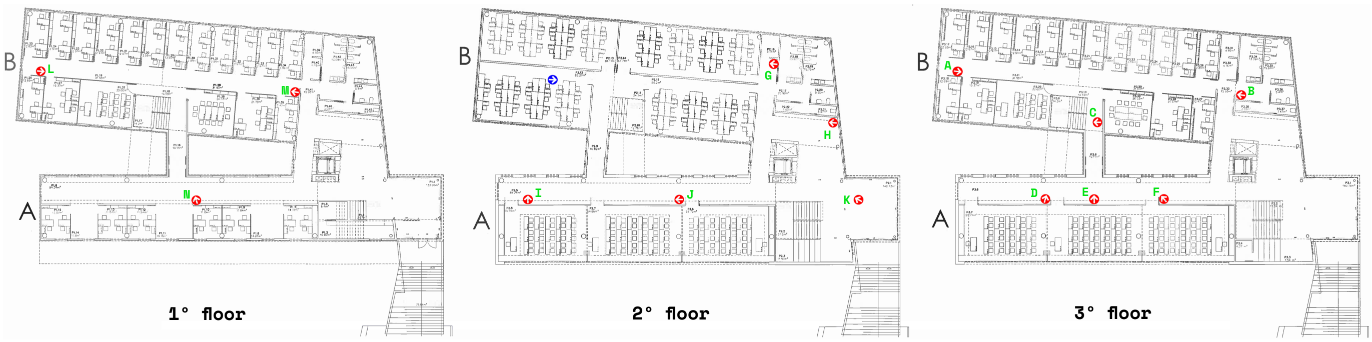

Figure 1. Bluetooth 5 node distribution for the three floors (blue: server node; red: clients).

3. Results

Table 1 shows the results in terms of the error rate of the received packets as well as the minimum, maximum, and average Receive Signal Strength Indicator (RSSI) values when transmitting 200 packets for each point. As it can be observed, good error rates were obtained for eight of the fourteen clients in spite of using a single-server node positioned in the second floor. In points B, D, F, and N, the maximum RSSI was less than −93; thus, considering that the theoretical sensitivity in Legacy (LE 1M) for the nodes was −96 dBm, it is logical that these were the points with the higher packet error rates. Additionally, it was at these extreme points where the use of the LE-coded mode allowed for a sensible decrease in the packet error rate.

Table 1. Error rate and RSSI values obtained at the different measurement points.

Parameter/Point	A	B	C	D	E	F	G	H	I	J	K	L	M	N
Error rate (%)	1	71	0	41	0	94	0	19	22	7	2	41	4	74
Min. RSSI (dBm)	−90	−94	−84	−98	−98	−98	−80	−99	−97	−98	−95	−99	−99	−98
Max. RSSI (dBm)	−80	−99	−62	−93	−81	−95	−63	−81	−82	−84	−87	−84	−89	−94
Avg. RSSI (dBm)	−84.9	−96.2	−67.8	−95.3	−86.3	−96.6	−69.6	−87.7	−86	−91.8	−90.2	−91.5	−92.9	−95.7

4. Discussion

It is important to consider that while the use of the LE-coded mode to increase the sensitivity was good for the considered indoor environment, it is also necessary to keep in mind that increasing the airtime can also saturate the channel, especially for advertisements, which are emitted in only three channels. Thus, Figure 2a,b compare the energy consumption and length of two advertisement events: one in the LE-coded mode (Figure 2a) and the other one in Legacy mode (Figure 2b). As it can be observed, the LE-coded event required roughly 3 ms more than in the Legacy mode, thus the latter almost doubles the former in length. This longer airtime also increases power consumption.

Figure 2c shows the channel occupation for the three advertisement channels (in green), wherein the values in gray show the average occupation of the channel. The tests were performed for four nodes that sent advertisements every 20 ms (the minimum value allowed) at 8 dBm within a 2 m range. Although it is an extreme case used just for testing the limits of the system, significant channel saturation can be observed.

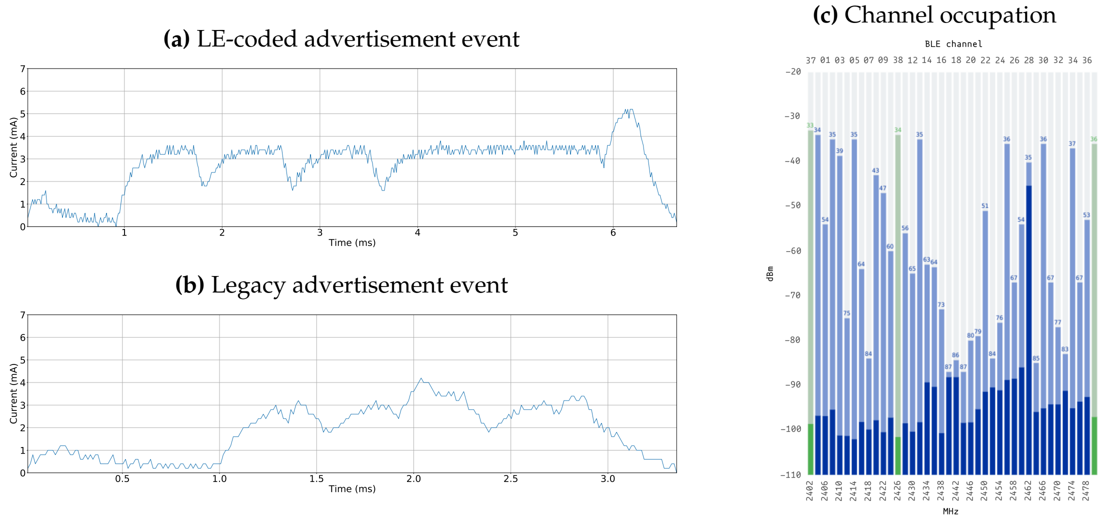

Figure 2. Airtime and channel occupation analysis.

In view of these results, it can be concluded that the system would benefit from the use of a second server node, as well as from determining the optimal position for the nodes. Moreover, the use of omni-directional antennas instead of the tested integrated directional PCB antennas would be beneficial in the evaluated indoor environment due to the reflections and would also provide full coverage to the entire building.

5. Conclusions

The purpose of this work was to analyze the coverage and performance provided by Bluetooth 5 in a large IoT indoor environment. The performed experiments show that the LE-coded mode offers notably better results than the Legacy version indoors due to the increased sensitivity. In terms of data propagation and reception, the covered distances considerably improve those obtained by most 2.4 GHz band technologies. Nonetheless, traditional 2.4 GHz technologies cannot be compared to LPWAN technologies as their unrestricted transmissions make them more suitable for the evaluated use case. The main concern to consider is to not abuse the advertisement events in the LE-coded mode, as they can saturate the available channels.

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