Reliability of Bluetooth Smart Technology for Indoor Localization System

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Abstract. The main objective of the paper was to test whether the devices compatible with Bluetooth Low Energy are reliable for indoor localization system. To determine the reliability of this technology several tests were performed to check if measured distance between Bluetooth transmitter and mobile device is close to the real value. Distance measurement focused on Bluetooth technology based mainly on received signal strength indicator (RSSI), which is used to calculate the distance between a transmitter and a receiver. As the research results show, the Bluetooth LE signal power cannot be the only reliable source of information for precise indoor localization.

Keywords: Bluetooth Low Energy · Bluetooth smart · Navigation system · Localization system · Accuracy of localization · Positioning techniques · RSSI

1 Introduction

In recent years the dynamic development of mobile devices can be observed. Mobile devices have been accepted by consumers and represent a strong branch of technology market. They give the users the opportunities similar to those offered by personal computers. Such devices can be used anywhere for e-mail, browsing the web, online banking, etc. Moreover, smartphones give also the possibility for individual navigation so that a user can be navigated to and from a particular address. The most widespread type of navigation is applied for outdoor purposes, however in the last few years there has been a need for navigation inside a building.

The outdoor navigation standards usually rely on GPS (*Global Positioning System*) satellites to determine the user position [1,2]. Despite the fact that this solution is very popular and precise for outdoor navigation, it is generally not well suited for indoor use. It is because:

– the GPS signal is strongly attenuated and disturbed inside the building,
– the GPS accuracy is not sufficient for such solution.

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The idea of indoor positioning is not completely a new approach, there are several solutions which base on different kinds of technologies [3–6]. Most of them use the waypoints calling also anchors whose position is static and determined. The example of such anchors inside the building can be Wi-Fi Access Points or other network devices [7–9]. Despite of growing popularity of these solutions none of them has become so far a universal standard for indoor localization. Although some indoor localization systems exist, but in most cases they are limited to the particular areas or used for highly specific purposes [10,11]. Wi-Fi has high power demands and is difficult to set-up and maintain than Bluetooth technology.

This paper focuses on Bluetooth wireless technology standard for exchanging data over short distances from fixed and mobile devices. Such technology has existed on the market nearly 20 years, however a new edition of this standard Bluetooth smart or Bluetooth Low Energy (BLE) from 2010 [12] open a new widely available possibilities of applying it for indoor positioning. The new versions 4.1 and 4.2 released in 2013–2014 introduced only some improvements and updates in software and hardware.

Compared to classic Bluetooth, BLE is intended to provide considerably reduced power consumption and cost while maintaining a similar communication range. The new standard defines also several profiles – specifications how a device should work in a particular application [13]. One of this applications is proximity sensing which should be designed to operate for a long period of time (months or even years) powered by a single coin cell battery.

Apart from the already mentioned works there are also other related works on using BLE technology. For example, the authors of [14] propose several empirical propagation models for BLE in different conditions: indoor/outdoor, line-of-sight (LOS). They also compare the propagation characteristics between BLE and Wi-Fi which indicates that BLE can be more accurate (around 27 percent) when is used in localization scenarios.

Paper [15] proposes a localization method which uses calculated values of a defined error function to estimate the positions of unknown transmitters. In this case the error function is based on a modified Root-Mean-Square-Error (RMSE) metric. The error function is calculated by the authors by using Received Signal Strength Indicator (RSSI) measurements at each point under consideration. Adding such error function is caused by unsufficient and inaccurate correlation between the received signal strength and the distance.

This paper focuses on reliability of using BLE technology for indoor localization, but there are also several solutions which use the older version of this standard [16,17]. These papers present the set of algorithms to transform Bluetooth data in order to estimate or improve the location process (fingerprinting-based positioning algorithms).

The main objective of the paper is to test whether the devices compatible with Bluetooth LE are reliable for indoor localization. To determine the reliability of this technology several tests will be performed to check if measured distance between BLE transmitter and mobile device is close to the real value. This measured distance is based on received signal strength indicator (RSSI), which represents the relationship between a transmission and a received power. On the receiver side RSSI is represented by an integer value used to calculate the distance between a transmitter and a receiver [18,19]. RSSI is also accessible in BLE by simply receiving a broadcasted message. In the present paper the RSSI is the only input to determine the location of a mobile device in an indoor environment.

The research results are carefully analyzed and explained if BLE technology is suitable enough for precisely indoor localization.

2 Bluetooth 4.0 Low Energy Standard

Bluetooth Low Energy operates on band 2.4 GHz with 40 channels located every 2 MHz (Fig. 1). The transmission speed is about 1 Mb/s and Gaussian Frequency Shift Keying (GFSK) modulation is used to select which data channels are to be utilized. Three of all available channels number 37, 38 and 39 are used to detect the devices [13]. Their frequency is not random and was selected to minimize the collision with channels 1, 6 and 11 in Wi-Fi standard. Selection of only the three channels with constant frequency (advertising channels) simplify and speed up the process of detecting other devices – the entire frequency spectrum scanning is no longer required.

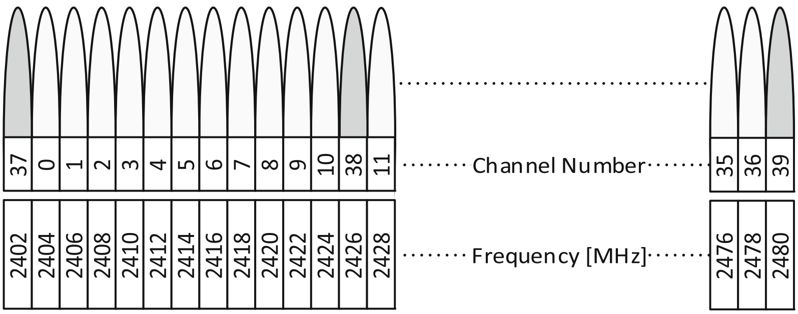

Fig. 1. Overview of Bluetooth LE channel spectrum

After detecting and connecting with the device, the remaining 37 channels are used for data transmission. BLE has four basic operate modes: master, slave, advertising and scanning. Advertising mode is used for cyclic sending advertising information from a particular device, needed to make a proper connection with this device. This mode can be also used to response to additional questions send by other devices. Scanning mode is used to receive advertising information that are sent by devices operating in advertising mode. Slave and master modes are used when two devices are already connected together. The principal function is to provide the possibility to read, write and poll. After connection the devices operating in advertising mode and scanning mode switch respectively to slave and master mode.

The Bluetooth LE stack is completely new solution and it is not compatible with the traditional Bluetooth stack (previous Bluetooth version). The stack protocol is divided into controller and host. The controller includes lower stack layers responsible for receiving the physical packets and radio operation. The host operates in upper stack layers and includes applications, and protocol of attributes. Moreover, the host runs the following services: L2CAP (*Logical Link Control and Adaptation Layer*), GAP (*Generic Access Profile*), SM (*Security Manager*), ATT (*Attribute protocol*), GATT (*Generic Attribute Profile*).

Thanks to several improvements, the energy consumption in BLE is much lower comparing to previous generations. First of all, it has the shorter work cycle which means that the device is more often in a sleeping mode. Additionally, using GATT profiles the module can send smaller segments of data in small packets which significantly increase the energy saving [20]. Another improvement for saving energy by the device is controlling the communication time. More precisely, when the communication between two devices is over the device switches to sleeping mode. In case of another data exchange the connection is quickly restored.

3 Test Bench and Research Procedure

The main point of the test bench is one of the commercially available Bluetooth LE transmitter (beacon node) which, in fact is also compatible with iBeaconl[1]. The research results can be extended also to beacon nodes of other vendors because of very similar construction. For the research requirements monitoring application for iOS[1] system was developed (Fig. 2). This application helps to collect the measurements of distance from beacon node and then saves the data that can be later analyzed.

The application allows also to change particular parameters of beacon nodes, such as: advertising interval, broadcasting power. Application enables to choose one of three power options: −30, −12, 4 dBm and three interval values: 50, 200, 1000 ms.

After preparing application for distance measurements collection, tests that check the accuracy of the results were conducted. The received data were then verified with the real distance which was determined with measurement tape. The research was divided into several scenarios. First type includes data collected in open area so that the fewest number of obstacles influenced the results. Therefore this phase was conducted outside the building away from disturbances [21]. The measurements were for distances 1 and 3 meters. The devices responsible for receiving data (smartphone or tablet) were located in three positions (Fig. 3), lying (in this position a device is parallel to the ground, screen to the top, upper side directed to BLE transmitter), vertical and horizontal positions.

The next scenario is a room simulating a natural environment with different obstacles (walls, other electronic devices, etc.) where beacon nodes can be

[1] iBeacon and iOS are trademarks of Apple Inc., registered in the U.S. and other countries.

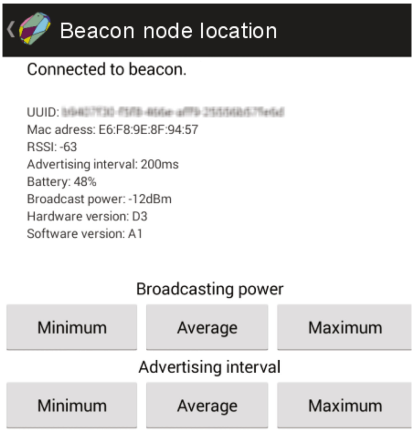

Fig. 2. Application for iOS system to configure and measure the distance from the Bluetooth LE transmitter

normally used. All the combinations of broadcasting powers of −12, 4 dBm and advertising intervals 200 and 50 ms were tested. The measured distance between the BLE transmitter and mobile device is the same as in scenario for open area.

The last test were conducted indoor for combinations of three broadcasting powers: −30, −12, 4 dBm and three values of advertising intervals: 1000, 200 and 50 ms. The mobile devices were set in the distance of 10 and 20 cm next to and then above the beacon node. All tests were conducted on Apple iPad mini and iPad mini Retina Wi-Fi.

4 The Research Results

In the first phase BLE transmitters were tested in open area to eliminate the influence of disturbances on collected measurements. For each set of parameters 30 samples were collected, which were used for preparing charts and statistics as follows:

– Broadcasting power: −12 dBm, advertising interval: 200 ms, distance: 1 m (Fig. 4 and Table 1),
– Broadcasting power: 4 dBm, advertising interval: 200 ms, distance: 1 m (Fig. 5 and Table 2),
– Broadcasting power: −12 dBm, advertising interval: 200 ms, distance: 3 m (Fig. 6 and Table 3),
– Broadcasting power: 4 dBm, advertising interval: 200 ms, distance: 3 m (Fig. 7 and Table 4).

During the research it was noticed that for parameters of beacon node: broadcasting power: −12 dBm, advertising interval: 200 ms, distance: 3 m and horizontal

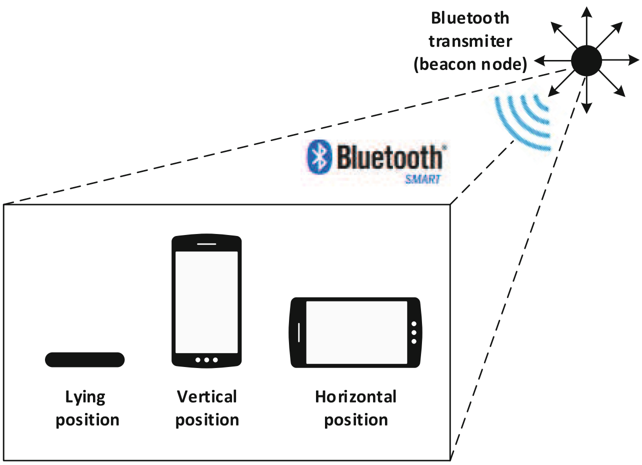

Fig. 3. Mobile device orientation in relation to beacon node

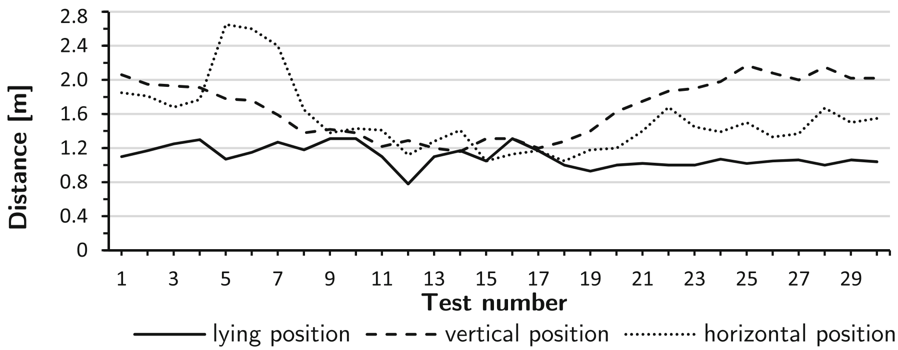

Fig. 4. Results for open area, broadcasting power: −12 dBm, advertising interval: 200 ms, distance: 1 m

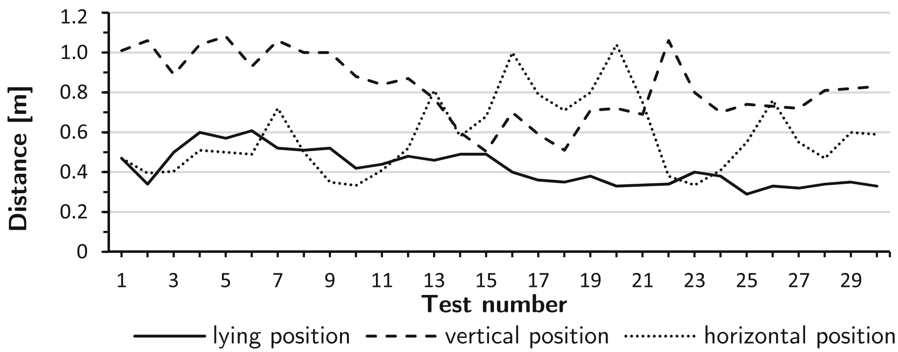

Fig. 5. Results for open area, broadcasting power: 4 dBm, advertising interval: 200 ms, distance: 1 m

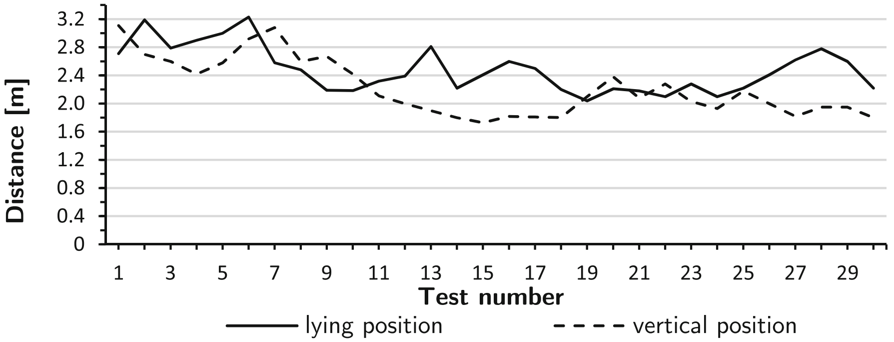

Fig. 6. Results for open area, broadcasting power: −12 dBm, advertising interval: 200 ms, distance: 3 m

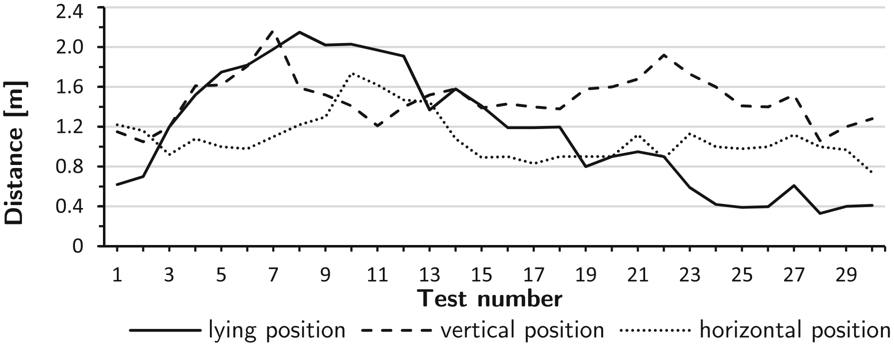

Fig. 7. Results for open area, broadcasting power: 4 dBm, advertising interval: 200 ms, distance: 3 m

Table 1. Measured values for open area, broadcasting power: −12 dBm, advertising interval: 200 ms, distance: 1 m

	Lying		Vertical		Horizontal	
	Distance [m]	RSSI [dBm]	Distance [m]	RSSI [dBm]	Distance [m]	RSSI [dBm]
Average	1.10	−74.8	1.67	−78.03	1.53	−77.1
Median	1.07	−74.5	1.75	−78	1.44	−77
Minimum	0.78	−78	1.16	−83	1.05	−83
Maximum	1.30	−70	2.17	−74	2.65	−73

orientation, the Core Location framework from iOS system supplying the information about the distance between the devices (beacon – smartphone) returned in this case the value −1, which according to framework specification means that the signal power was too low to determine the right distance. That is why Fig. 6

Table 2. Measured values for open area, broadcasting power: 4 dBm, advertising interval: 200 ms, distance: 1 m

	Lying		Vertical		Horizontal	
	Distance [m]	RSSI [dBm]	Distance [m]	RSSI [dBm]	Distance [m]	RSSI [dBm]
Average	0.42	−67.13	0.82	−72.53	0.58	−70.23
Median	0.40	−66.5	0.81	−72.5	0.54	−70.5
Minimum	0.29	−76	0.50	−79	0.33	−79
Maximum	0.60	−62	1.08	−68	1.04	−62

Table 3. Measured values for open area, broadcasting power: −12 dBm, advertising interval: 200 ms, distance: 3 m

	Lying		Vertical		Horizontal	
	Distance [m]	RSSI [dBm]	Distance [m]	RSSI [dBm]	Distance [m]	RSSI [dBm]
Average	2.49	−80.93	2.22	−79.93	—	—
Median	2.44	−81	2.09	−80	—	—
Minimum	2.04	−84	1.73	−83	—	—
Maximum	3.23	−78	3.11	−77	—	—

Table 4. Measured values for open area, broadcasting power: 4 dBm, advertising interval: 200 ms, distance: 3 m

	Lying		Vertical		Horizontal	
	Distance [m]	RSSI [dBm]	Distance [m]	RSSI [dBm]	Distance [m]	RSSI [dBm]
Average	1.15	−73.93	1.48	−76.97	1.08	−74.8
Median	1.16	−74	1.49	−77	1.00	−74
Minimum	0.33	−81	1.05	−81	0.74	−83
Maximum	2.15	−64	2.16	−72	1.73	−71

and Table 3 do not contain the measurement for these parameters and horizontal orientation.

The next series of tests were conducted indoor to simulate more real conditions where beacon nodes operate. As in the previous case, 30 samples for each configurations were collected. Table 5 presents the results of the conducted research.

Having established that for greater distances the measurements are not accurate, tests for smaller distances 10 and 20 cm were performed (Table 6). Such distance is an alternative for NFC (*Near Field Communication*) technology.

Table 5. Measurement results for indoor environment for different orientations (Broadcasting Power – BP, Advertising Interval – AI, Distance – D)

	Measured distance [m] for orientations:		
	Lying	Vertical	Horizontal
BP: –12 dBm, AI: 200 ms, D: 1 m	1.09	1.93	1.42
BP: –12 dBm, AI: 200 ms, D: 3 m	1.62	2.31	2.1
BP: –12 dBm, AI: 50 ms, D: 1 m	5.13	9.83	9.46
BP: –12 dBm, AI: 50 ms, D: 3 m	8.43	14.46	2.49
BP: 4 dBm, AI: 200 ms, D: 1 m	0.14	0.97	0.26
BP: 4 dBm, AI: 200 ms, D: 3 m	0.33	0.66	0.72
BP: 4 dBm, AI: 50 ms, D: 1 m	0.67	2.25	1.27
BP: 4 dBm, AI: 50 ms, D: 3 m	1.59	3.81	3.39

Table 6. Measurement results for a short distance and different advertising intervals (Broadcasting Power – BP, Distance – D, Location – L)

	Measured distance [cm] for advertising intervals:		
	1 s	200 ms	50 ms
BP: –30 dBm, D: 10 cm, L: next to	42.9	22.5	19.9
BP: –30 dBm, D: 10 cm, L: above	35.1	46.3	44.7
BP: –12 dBm, D: 10 cm, L: next to	7.1	7.6	13.5
BP: –12 dBm, D: 10 cm, L: above	22.2	8.5	8.1
BP: 4 dBm, D: 10 cm, L: next to	7.9	5.3	3.8
BP: 4 dBm, D: 10 cm, L: above	5.1	6.7	9.5
BP: –30 dBm, D: 20 cm, L: next to	47.6	60.1	59.9
BP: –30 dBm, D: 20 cm, L: above	43.1	42.8	38.4
BP: –12 dBm, D: 20 cm, L: next to	54.5	70.4	13.6
BP: –12 dBm, D: 20 cm, L: above	19.8	8.3	15.9
BP: 4 dBm, D: 20 cm, L: next to	15.1	5.5	8.7
BP: 4 dBm, D: 20 cm, L: above	7.2	12.3	20.2

Additionally two the most possible relative positions were taken into consideration, which means when the mobile device is above and next to BLE transmitter.

The conducted research shows that increasing the number of sent packets from Bluetooth transmitter within 1 second resulted in reducing the differences between following readings, and decreasing the signal strength resulted in large drop of the measured distances. The most appropriate results were achieved for average signal power and for the highest frequency of transmission.

5 Conclusion

Comparing the received results for longer distances it can be stated that especially for indoor environment the results are not very precise, and in consequence they cannot be applied for exact positioning. To determine indoor position the distance of at least several Beacons is required that are next used for searching the user position. The differentiation in measurement values however is so great, that it makes in some cases it impossible to determine such point.

The authors intended also to check if the device orientation has influence on the distance readings. It has been proved that an additional obstacle (e.g. a user hand), can decrease significantly the accuracy of measurements. It is because a user holds a device in various positions and at the same time Bluetooth antenna can be covered and the readings are then inaccurate.

Distance measurement focused on Bluetooth technology based mainly on received signal strength indicator RSSI, which is used to calculate the distance between a transmitter and a receiver. As the measurements results of RSSI shows, using this parameter for distance calculations can be problematic. A good correlation between distance and RSSI is observable only in case when a distance between a beacon node and mobile device is very small, especially in open area. Above the value of 1 m, huge fluctuations of measured distance were noticed.

According to the observations, Bluetooth LE signal power cannot be the only reliable source of information for precise indoor localization. The authors in their future work intend to focus on issue referring to the use of additional signals and information form the indoor environment in order to increase the accuracy of indoor positioning.

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