Deployment and analysis of Bluetooth low energy network

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Abstract. Along with the development of modern communication technologies such as 4G and 5G, Internet of Thing (IoT) technologies are being implemented more widely. The need for remote monitoring of environmental and patient parameters can be realised by means that represent IoT technologies. The localisation of mobile sensor nodes for low power IoT can be realised by tracking the Received Signal Strength Indicator (RSSI) values. This paper examines the RSSI values of sensor nodes in the Bluetooth Low Energy network for IoT.

1. Introduction
Together with the active proliferation and improvement of 4G and 5G networks, those for the Internet of Things (IoT) are also being developed. One of the designations of IoT networks is to supervise environmental parameters such as temperature, pressure, humidity, lighting and more [1]. Distant surveillance of diverse parameters is becoming busier in modern life, and the necessity for this is especially manifest during emergencies [2].

The monitoring of the condition of the environment or patients can be realised with the help of contemporary IoT sensor networks, which allow intermittent surveillance of parameters from both static and movable sensor nodes. In definite occasion, it may be requisite to locate the sensor nodes in the network. One of the ways to accomplish this with a network of low-power sensor units is to track the values for the Received Signal Strength Indicator (RSSI).

This paper presents the deployment of a physical Bluetooth Low Energy (BLE) sensor network for IoT and a study of the RSSI values derived from the end sensor units in the network.

2. Related works
The study in [3] presents a new method of localisation in a vehicle with high-precision, based on a functional study and full use of multi-channel RSSI in BLE technology. The objective of the research is to accurately localise the occupant in the vehicle. A hierarchical computational algorithm has been suggested to accomplish the desired precision. The conclusions show that the suggested method distinguishes the location of the driver or occupants with an accuracy ranging from 86.80% up to 92.02% for each seat for the Nexus phone with a standard deflection of 2.64% and from 85.43% up to 93.33% for Huawei phone with a standard deflection of 3.07%.

In [4] an exhaustive experimental investigation of RSSI values in a dense indoor BLE network presented. The main purpose of the study is to assign the deflections in RSSI bred by the noise effects in the environment and to elaborate a model for dissemination in the radio surrounding to minimise the evaluation of distance and localisation error. There is an average error in estimating the position of 1.32m with a deviation of 10dBm in the RSSI values, according to the experimental analysis. Also the...
environmentally specific radio constants strongly influence the accuracy of estimating the distance and location of the BLE units.

In [5] examined the positioning accuracy of various commercial BLE devices. The RSSI values from sensor knots are used to assign distances without using a filter, to represent the raw productivity of the devices used for the purposes of the study. The results show a deviation in accuracy from 0.07m to 7.81m.

In [6] proposed an RSSI Gaussian mixture model (GMM) for performing indoor localisation using BLE sensors. GMM used to overcome the drastic fluctuations in RSSI and to present the distributed values more accurately. Significant improvements in terms of localisation accuracy the proposed model ensure, according to the experimental results.

In [7], a solution for an indoor localisation system based on the BLE standard investigated using RSSI values. The research considers RSSI based BLE indoor positioning. There are implemented five filtering algorithms: median, mode, single direction outlier removal (SDOR), feedback and shifting. The experiments show that indoor BLE-based localisation depends on different conditions, and improvement of the localisation system can be achieved by implementing more accurate filters.

In [8] presented an inverse model of the distance between two BLE devices depending on the measured RSSI values and Packet Error Rate (PER). A model of the accuracy of forecasting the distances calculated by RSSI and PER measurements presented.

The considered researches investigate the BLE standard, and examine the values of RSSI obtained from the end sensor nodes. The RSSI values in these studies are considered in order to be used to determine the location of the end nodes in the network. Alike to the research works considered, current paper examines the received RSSI values from end sensor nodes, based on the BLE standard. Tracing the variation of the RSSI values for static sensor nodes located at different distances from the master device and for mobile nodes that move at different speeds in a centralised BLE sensor network, is the major purpose of the study.

3. Bluetooth Low Energy (BLE) network deployment, experimental scenario and results

The physical building of the BLE network done with RaspberryPi 4 Model B [9] board with Raspbian operating system working as BLE master device, with built-in BLE transceiver and Texas Instruments multi-standard sensor nodes – CC2650STK [10].

The Bluepy program can be used to start the RaspberryPi to work as a master BLE device. Bluepy requires the installation of the Python programming language for its operation. Likewise the installation of libglib2.0-dev library required. Reading data from the end sensor nodes and listen to the communication medium on which the data transmitted, can realised after configuring the master BLE device. Thus, information can be obtained about the address of the device (figure 1-1), the measured RSSI values for the nodes in the network (figure 1-2), the name of the sensor node (figure 1-3), the transmitting power (figure 1-4) and manufacturer information (figure 1-5).

**Figure 1.** Captured BLE packets on the communication medium.
The master BLE device can receive information from the CC2650STK sensor nodes after they are configured to work with the BLE standard.

The star topology by connecting the end sensor nodes and the master one was realised to examine the alteration in RSSI values. According to figure 2, with 1 is marked the master device and with 2 the sensors that are used for experiments with static sensor nodes. Different experiments with 1, 2, 3, 4, 5 and 6 static nodes performed, where for every one the nodes are located at distances from 1m to 10m from the master device. The outcomes from the experiments performed, for static nodes, are in table 1.

![Figure 2. Used physical topology for experiments with static nodes.](image)

**Table 1.** Results for RSSI values from experiments with static sensor nodes.

| Sensor Nodes | Distance to BLE Master Device [m] |
|--------------|----------------------------------|
| 1            | 1  2  3  4  5  6  7  8  9  10 |
| 2            | 1  2  3  4  5  6  7  8  9  10 |
| 3            | 1  2  3  4  5  6  7  8  9  10 |
| 4            | 1  2  3  4  5  6  7  8  9  10 |
| 5            | 1  2  3  4  5  6  7  8  9  10 |
| 6            | 1  2  3  4  5  6  7  8  9  10 |

The experimental results presented in table 1 for all tests performed manifested that the RSSI values are not constant. For 1 node the results show that as the distance of the sensor from the master device increases, the received RSSI values deteriorate. However the value at 10 meters is significantly
better than the previous ones. Although only one device is transmitting on the communication environment which is not loaded, the decline in the previous values may be due to external sources of interference. The measured RSSI values for one of the nodes are quite close to the values in the tests with one device, according the results for 2 sensor nodes. For the second node it is seen that the derived values are considerably lower. As the distance from the master device increases, the resulting RSSI values worsen. The trend that at closer distance to the service device the obtained RSSI values are better is confirmed from the other tests with 3, 4, 5 and 6 sensors. The measured values for RSSI decline more and more when the distance from the master device and the end nodes number in the network increase. Because of the load in communication medium and the simultaneous transmission of the end nodes in it there is caused interference and this decrease the quality and strength of the signal. A significant difference between the initially reported results and those reported at the end observed when the distance between the static sensors and the master device increases.

Similar experiments were performed with mobile nodes. According to figure 3, with 1 is marked the master device and with 2 the mobile nodes. The movement of the sensors is done as the nodes are arranged in a cart that moves. Different experiments with 1, 2, 3, 4, 5 and 6 mobile nodes performed, where for every one the nodes move at a speed of 0.5m/s to 3m/s. The outcomes from the experiments conducted, for mobile nodes, are presented in table 2.

![Image](image_url)

**Figure 3.** Used physical topology for experiments with mobile nodes.

To examine the effect of interference between devices on the RSSI values gained by the coordinator for both static and mobile devices, the sensors are placed next to each other.

The results from the experiments for all tests with mobile sensor nodes shown in table 2 are also inconsistent in regard to the obtained RSSI values. At lower speeds is visible that the obtained RSSI values are better according to the results with 1 mobile sensor. As the speed amplifies, aggravation of the obtained values reported. The RSSI values for one of the nodes are close to the values reported for the first node, according the results for 2 mobile sensor nodes. For the second node it is seen that the values are considerably lower. This is bred by the load on the communication environment and the emerged interferences. The trend when the sensors moving at a lower speed, the received RSSI values are better is confirmed from the other tests with 3, 4, 5 and 6 sensors.
The experiments show deterioration of the reported RSSI values with increasing the number of sensors and the load on the communication environment. The received RSSI values decrease smoothly with increasing of the speed of the nodes. This is caused by the receiving and transmitting delay of RSSI values from the mobile nodes to the main device while movement.

4. Conclusion
This paper represents the deployment of Bluetooth Low Energy sensor network. The examination of alterations in the received RSSI values for static sensor nodes located at different distances from the master device and for mobile nodes moving at different speeds done. Experimental results for the RSSI with static sensor nodes show that with increasing distance between the end nodes and the master device, the received values aggravates with considerable changes. Experimental results for the RSSI with mobile sensor nodes show that with increasing the speed of end nodes, the received values aggravates, but the change in the results is smoother. For both static and mobile nodes sustained the tendency of aggravation of RSSI values with enlarging number of end sensor nodes in the network.

References
[1] Dinev D Z 2019 Simulation Framework for Realization of Horizontal Handover in Li-Fi Indoor Network, *IEEE XXVIII International Scientific Conference Electronics (ET)*, Sozopol, Bulgaria, 2019, pp 1-4, doi: 10.1109/ET.2019.8878509
[2] Ericsson Mobility Report, June 2020. Available at: https://www.ericsson.com/en/mobility-report/reports/june-2020, Last visit on 28.07.2020
[3] Yuan G, Ze Z, Changcheng H, Chuanqi H and Li C 2020 In-vehicle localization based on multi-channel Bluetooth Low Energy received signal strength indicator, *International Journal of Distributed Sensor Networks*, 16(1), doi: 10.1177/1550147719900093 journals.sagepub.com/home/dsn
[4] Subhan F, Khan A, Saleem S, Ahmed S, Imran M, Asghar Z and Bangash J I 2019 Experimental analysis of received signals strength in Bluetooth Low Energy (BLE) and its effect on distance and position estimation. *Trans Emerging Tel Tech.* e3793. https://doi.org/10.1002/ett.3793
[5] Fachri M and Khumaidi A 2019 Positioning accuracy of commercial Bluetooth low energy beacon. *IOP Conf. Ser.: Mater. Sci. Eng.* **662** 052018, https://doi.org/10.1088/1757-899X/662/5/052018

[6] Malekzadeh P, Salimibenii M, Atashi M, Barbulescu M, Plataniotis K N and Mohammadi A 2019 Gaussian mixture-based indoor localization via Bluetooth low energy sensors, *IEEE SENORS*, Montreal, QC, Canada, pp 1-4, doi: 10.1109/SENSORS43011.2019.8956950

[7] Mussina A, and Aubakirov C 2018 RSSI based Bluetooth low energy indoor positioning, *IEEE 12th International Conference on Application of Information and Communication Technologies (AICT)*, Almaty, Kazakhstan, pp 1-4, doi: 10.1109/ICAICT.2018.8747020

[8] Conti M 2017 Real time localization using Bluetooth low energy, *Bioinformatics and Biomedical Engineering. IWBBIO 2017. Lecture Notes in Computer Science* **10209** ed I Rojas and F Ortuno (Springer, Cham), https://doi.org/10.1007/978-3-319-56154-7_52

[9] Raspberry Pi 4 Tech Specs, Available at: https://www.raspberrypi.org/products/raspberry-pi-4-model-b/specifications/, Last visit on 28.07.2020

[10] SimpleLink Bluetooth low energy/Multi-standard SensorTag. Available at: http://www.ti.com/tool/ CC2650STK?keyMatch=CC2650STK&tisearch=Search-EN-everything&usecase=GPNN. Last visit on 28.07.2020

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