Design BLE Hub application for Positioning Accuracy of iBeacon Technology in Indoor Environments

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Abstract: - Global positioning and location tracking have become one of the common applications in various industries, especially in supply chain and logistics, smart cities, public transport systems etc. Location and tracking applications in the outdoor environment use Global Positioning System (GPS) to track the location of a device. For example, am application installed on a smartphone can use the phone location and generate maps and routes from the device location to a specific location as requested. However, location tracking and positioning in indoor environment have to rely on other technologies as the area covered is very small compared to GPS in outdoor environment. In addition, GPS may not be able to provide accurate information in an indoor environment. Currently, indoor location positioning and tracking is mainly based on the technologies such as WiFi, RFID, Zigbee, Bluetooth Low Energy etc. Similar to these indoor positioning technologies, iBeacon, is new device-to-device communication technology that relies on Bluetooth Low Energy (BLE). iBeacon technology is used in BLE communication for determining the distance between two devices. The Received Signal Strength Indicator (RSSI) is the strength of the beacon's signal as seen on the receiving device such as smartphone, used for positioning and location tracking. However, there are many signals' distortions and/or obstructions such as water, people body, thick walls and etc. in indoor communication between devices, which can affect the range and RSSI while estimating the distance between two communication devices. To address this issue, BLE Hub application design for smartphone, which can reduce distortions and/or obstructions of iBeacon signals is provided and discussed.

Key words: *Global positioning, location tracking, Global Positioning,System (GPS), Bluetooth Low Energy (BLE), Received Signal Strength Indicator (RSSI)*

1. Introduction:

With rapid use of Information and Communication Technologies (ICTs), people are surrounded by a variety of electronic communication devices [1]. Most of the daily life of the majority of people is usually spent in indoor environments such as schools, universities, office spaces, shopping malls etc. In such indoor environments, location tracking and positioning can be one of the major challenges, as GPS may not be effectively implemented within the indoor environment due to various obstructions which affects the communication between satellites and devices. Therefore, instead of GPS, other technologies such as Wi-Fi, ZigBee, and NFC radio frequency identification (RFID), and Bluetooth low energy (BLE) wireless communication are preferred for indoor positioning [2-4]. BLE has become one of the most preferred technologies for indoor positioning due its various features and functionalities including ease of use, openness, and efficient battery life for many years [5]. BLE uses high bandwidth for communication between various electronic devices and consumes relatively low power. Personal Area Networks (PANs) can be established using the Bluetooth technology with minimal efforts for configuration and setting up the network [1]. In addition, BLE enabled with iBeacon technology is a new technology that enables communication between various devices such as smartphones and tablets, when available in close proximity [6]. The communication is enabled by BLE (with iBeacon) enabled devices by emitting passive signals. Information can be transmitted to between the people with BLE enabled devices, depending on the distance between them [1].

Accurate positioning has been one of the major issues concerning location-based services. Unlike outdoor environment, indoor environment has various obstacles such as walls, other communicative channels, furniture, objects etc. which can affect the communication process between the devices. In addition, Radio-Frequency signals such as WiFi, RFID etc. can distort beacon signals and affect their rage in indoor environment. Beacon location and signal is very important in enabling indoor positioning, as it propagates the signal, improves accuracy in estimating the distance between the iBeacon and device such as smartphone. Considering these aspects, this paper proposes a solution to address the issues of distortions in indoor communication for location positioning by

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designing a BLE hub smartphone application. Accordingly, this paper is divided in to three sections. The first section discusses Background and Related Work of iBeacon technology and reviews different articles using iBeacon for indoor-positioning. The second section explains the design of BLE hub Smartphone application. Finally, this paper concludes with a brief summary of the work.

2. Background and Related Work

Location Systems Based on Bluetooth Low Energy (BLE).

Various studies related to the BLE-based location systems and their applications can be identified in the literature. The BLE-iBeacon based application installed in a person's mobile device continuously sends the received beacon IDs and their RSSI values to a remote server, which is used for estimating the location of the various persons and their devices [7]. Focusing on this innovative technology, Lin et al. [8] proposed a solution for identifying the patients in an overcrowded emergency room. The patients in the waiting list may move around the hospital, as the emergency room may be overcrowded. Therefore, a mobile indoor positioning system based in iBeacon technology was proposed using which doctors and nurses can find the real-time locations of the patients within the hospitals. In a different context, Zhao et al. [9] used iBeacon technology in warehouse management. The items stored in the warehouse were attached with beacon transmitters, and the beacon signal receivers are stored in the warehouse. Thus, items can be accurately located by the warehouse management system by RSSI fingerprint matching. In addition, the study [9] has found that using BLE iBeacon technology, operations such as order-picking and stock-taking processes can be effectively improved with high accuracies. Similarly, Wu et al. [10] used iBeacon devices for improving accuracy of indoor localization through inertial sensors. iBeacon localization process corrects the accumulated errors of indoor localization through inertial sensor, whenever a user comes into the vicinity of iBeacon device clusters. The study has identified that 95% of the errors were within the rage of 3.5 meters. Martin et al. [11] investigated the effectiveness and efficiency of iBeacon technology in providing accurate results. As a part of investigation, a mobile user interface (UI) was designed for users using which settings in Beacon can be adjusted (TX power and frequency). It was identified that change in settings affected the distance estimates. In addition, the accuracy of the indoor positioning was improved by using trilateration in finger-print based environment using the technique, INTRI by He et al. [12]. The signal strengths at each access point is measured using which distinct contours of equal signal strengths are formed in the fingerprint region. Then, the user's location can be located using the concept of trilateration by correlating the user's signal vector with the number of contours.

Implementations of Bluetooth Mesh Networking

The network design for communication has to consider various factors such as mode of communication, topology, types of communication etc. Beacon technology, for instance, supports unidirectional communication, and Bluetooth technology supports bidirectional communication. However, in this study at implementation time of network communication network was limited to a star topology [13]. The major issue identified in this process was related to Bluetooth Mesh-standard, which was not designed to support real-time communications over multi-hop mesh networks [13]. The solution of the limitation by using the Multi-hop Real-time BLE (MRT-BLE) which is a real-time protocol built on top of the BLE standard, that can use in implementing mesh networks with BLE devices. MRT-BLE protocol is connection-oriented, which can achieve higher throughput compared to a connection-less approach [14]. In addition, the MRT-BLE model allows to service 37 channels for hopping, whereas connection-less models allow to service only three channels [14].

Different mesh protocols were developed by the researchers for using BLE technology. For instance, CSRmesh (a proprietary flood-based mesh protocol for BLE) was developed by CSR Inc. in 2014 [15]. A total of 65535 nodes per network can be supported by using this protocol. In addition, the propagation delay between nodes can be less than 15ms [15]. The packet delivery ratio of different setups using CSRmesh protocol was studied by Zenker et al. studied developed by Nordic Semiconductor Inc. [15]. Similarly, nRF OpenMesh (a flood-based mesh protocol for BLE) is another protocol which is based on the Trickle algorithm [16]. It considers node density and value update frequency as metrics, using which rebroadcasting behavior of mesh nodes can be dynamically controlled through nRF OpenMesh Trickle algorithm [26]. An Opportunistic Routing (OR)-based mesh protocol was another protocol identified, which is denoted as BLEmesh, was proposed by Kim et al. [17]. However, the official Bluetooth mesh networking specifications was released in 2017, by the Bluetooth Special Interest Group (SIG) [18]. Using BLEmesh protocol, a source node adopts an opportunistic way in selecting a set of nodes for forwarding, after broadcasting the message [17]. It is interesting to note that the OR-based protocols require less packets to broadcast in order to accomplish the transmission, compared to conventional routing protocols for wireless mesh networks, resulting in low power consumption. Advertising communication modes based on flooding technique is used by the Bluetooth Mesh. This approach is used by the majority of BLE mesh protocols.

End to End latency, power consumption, and Packet Delivery Ratio (PDR) were considered for analyzing both performance flooding and connection-oriented networking in [19]. Though the conclusion was not definitive, the results reflected that no mesh BLE approach could simultaneously offer optimal performance for all metrics. Therefore, the approach has to be selected based on the specific requirements of the application being designed. Accordingly, using both advertising and connection modes, an innovative approach called Bluetooth Now paradigm was proposed. In this approach, nodes run in a connected mode for sending periodic and non-time-sensitive data to the sink, and they also switch to flooding mode for delivering sporadic and urgent data. Two categories including academic and proprietary were used for identifying BLE Mesh network solutions [20].

Bluetooth Beacon Technology

Businesses have been increasingly adopting Bluetooth iBeacon technology in providing proximity-aware services for consumers, and for various operations in industrial environments. The iBeacon technology was introduced in Bluetooth version 4, for supporting BLE. The packets transmitted by iBeacon contains an identifier and several bytes of information [21]. Three “pseudo-standards” including BLE iBeacon [22], Eddystone [23], and AltBeacon [24] are used for Bluetooth beacons. BLE iBeacon technology has become more popularity after the release of Apple’s iBeacon protocol in 2013 [22]. After that, it has followed by the release of AltBeacon (a protocol specification) in 2014, by Radius Networks Inc.; and Eddystone (an extended specification of the standard) in 2015, by Google Inc. All the three standards were related to broadcasting BLE advertising packets.

Focusing on the functionality, a Bluetooth scanner decodes the content and takes corresponding actions, as soon as it receives an advertising packet. However, the formats of the packets message differ in standards [22-24]. Eddystone has four message formats for different purposes, which include: Eddystone-UID, Eddystone-EID, Eddystone-TLM, and Eddystone-URL. In addition, Eddystone data frame contains a 16-byte beacon UID (10 bytes namespace ID and 6-byte instance ID). The purpose of Eddystone-TLM is to send small pieces of data about the beacon, such as battery voltage, device temperature, and counts of broadcast packets [25]. The purpose of Eddystone-URL message is to broadcast an URL that redirects the receiver to a website, in a mobile device [25]. Similarly, iBeacon message consists of 4 fields, which include: UUID, Major, Minor, and TX power. By comparing RSSI of the iBeacon message and the value of TX power in the message, the receiver can determine the approximate proximity to the iBeacon transmitter [22]. AltBeacon was designed for an open and interoperable specification. The message format of AltBeacon includes Manufacturer ID, Beacon Code, Beacon ID, and Reference RSSI [24]. Compared to iBeacon, AltBeacon message has more user data bytes, which delivers more data per message, as shown in figure 1.

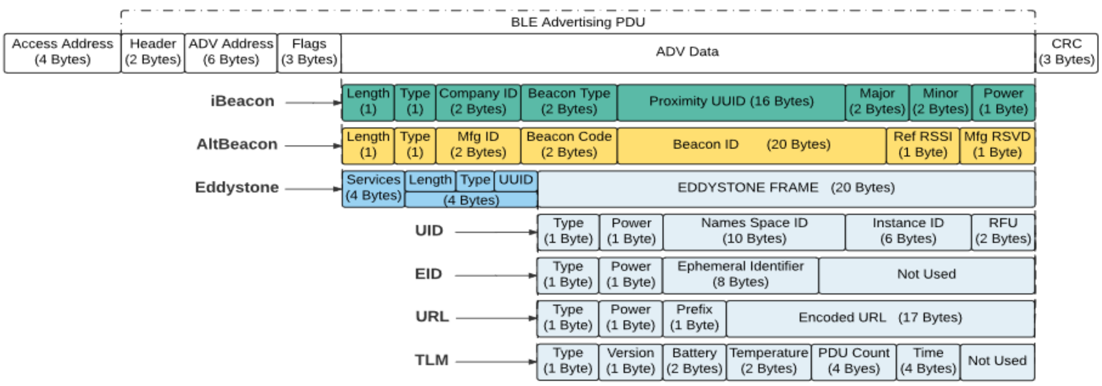

Figure 1: Structure of iBeacon, AltBeacon and Eddystone beacon protocols.

Detection and Locating Transmitters

BLE communication is based on iBeacon technology, which is a one-way discovery mechanism. Small data packets in pre-specified intervals ranging from 20 to2000 ms are transmitted using iBeacon technology [26]. In a BLE-based solution, when the device such as smartphone detects an iBeacon, based on the information (signal's strength and the value of major and minor values) from the message, different techniques and methods can be implemented to find an approximate distance from the iBeacon. The distance between the transmitting beacon and the received device such as smartphone can be estimated with various ranges categorized, which can result in one of four proximity states [26] shows in figure 2:

- *Immediate: A state reflecting high confidence level that the device is very close to beacon.*
- *Near: A state reflecting a distance of one to three meters between the device and beacon, without any obstacles in between.*
- *Far: A state reflecting a distance of three to 70 meters between the device and beacon, which may include physical obstacles in between, and indicates low transmission power, low confidence in accuracy.*
- *Unknown (or out of range): A state, where the transmitter cannot be identified.*

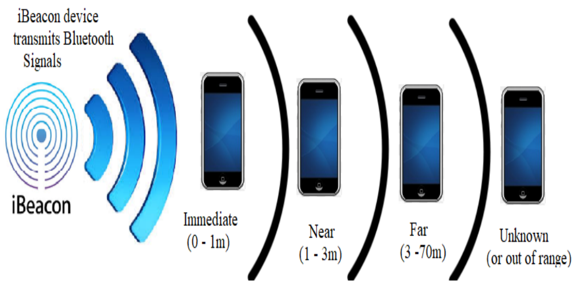

Figure 2: Distance between the transmitting beacon and the received device.

There are various advantages of using iBeacon, as it is energy efficient, small-sized transmitter. Transmission power and the transmission rate are the two factors based on which the battery life of an iBeacon can be estimated [27]. The output power of the broadcasted signals is considered as transmission power, which can impact on the communication range between iBeacon and receiver device [27]. The advertising interval of iBeacon broadcasting signals is referred as transmission rates. Increasing transmission power makes signal stable, but decreases battery life; whereas increasing transmission rates increases the battery life but communication with users' devices may decrease, resulting in poor analysis of location positioning. Both factors can be tuned according to the requirements by modifying the configuration settings.

A standard beacon has an estimated range of 70 meters; however, long-range beacons can reach up to 450 meters [28]. The maximum range of an iBeacon transmission depends on the beacon's location and placement, and its transmission power (Tx power). However, distortions factors can affect the broadcasting signal. Therefore, installing beacons in locations with minimal distortions is essential for achieving maximum range for transmission. However, unavoidable obstructions such as people, water, thin walls and furniture can affect the signal's strength and decreases the signal range. Therefore, the estimated distance is just an approximation of real distance. This paper Focuses on the impact of obstructions, it shows the effects of obstacles in indoor environment on signal propagation and fluctuation, then explaining how the BLE Hub smartphone application can solve the problems identified and provide the positioning accuracy.

3. BLE Hub Smartphone Application Design

BHSA (BLE Hub Smartphone Application) Overview.

Positioning accuracy is one of the major issues affecting the location-based services. Location accuracy between smartphones and beacons was identified as the major areas of research in few studies. For instance, logarithmic model was used in [29] to estimate the average error in distance between smartphone and iBeacon. The study has identified an average error of 1.09 m for a range from 1m (meter) to 9m and 1.75m for a range from 1m to 20m. In addition, a similar study [30] has indicated that the beacon based on micro-location system in indoor environment can be used to locate a user with an average error of 0.27 meters to user location. Accordingly, another study [30] reported very accurate positioning results by using iBeacon in four scenarios to locate smartphone device in indoor environment. In contrast to the above mention studies, it was identified that the iBeacon may not give accurate results after three meters, because as signal propagation and fluctuation or obstruction may affect the accuracy [31].

A bidirectional communication for broadcasting messages between smartphone and iBeacon is used by BHSA. iBeacon signal includes UUIP and TX power and RSSI information for estimating the distance between devices. The purpose of using BHSA is to minimize the impact of obstruction for iBeacon signals in indoor environments. Figure 3 presents an overview of communication process between smartphones and iBeacon.

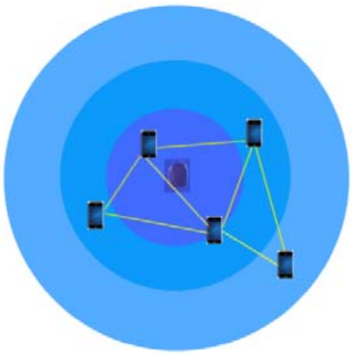

Figure 3: overview of BHSA communication process.

UUID information of iBeacon is used to identify the iBeacon source that has been used in message broadcasting among smartphones through BHSA. As discussed earlier, the distance between iBeacon device and smartphone can be estimated using TX power, and the current RSSI of the received signal from a smartphone. The TX power (or the measured power) information in the beacon protocol is the strength of the signal measured at a distance of 1m from the source device. It is preconfigured in factory settings as read-only constant and used for estimating how close is the smartphone to iBeacon device. RSSI, as explained earlier, is the strength of a beacon's signal, detected by receiving smartphone device.

BHSA Scenario Description

Due to the obstructions such as walls in indoor environment, distortions in the signal propagation may be experienced as shown in figure 4.

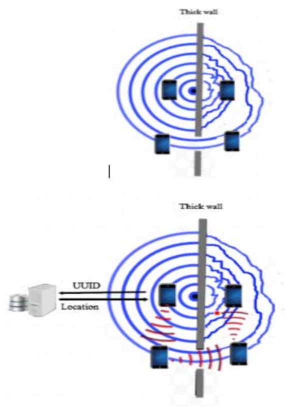

Figure 4: BHSA scenario description and solution

Therefore, RSSI becomes weak depending on the obstructions and the larger distance of the device (receiver of RSSI and TX power). Distortions and fluctuations in signal propagation can be observed from figure 3, reflecting how RSSI gets unbalanced, when an obstruction (wall) is in between the iBeacon and smartphone, compared to clear signal propagation when there is no obstruction.

Design of BHSA software

Design approaches such as procedures established, algorithms used in the design and development of BHSA system are explained in this section. Accordingly, the UML flow chart is presented in figure- 5.

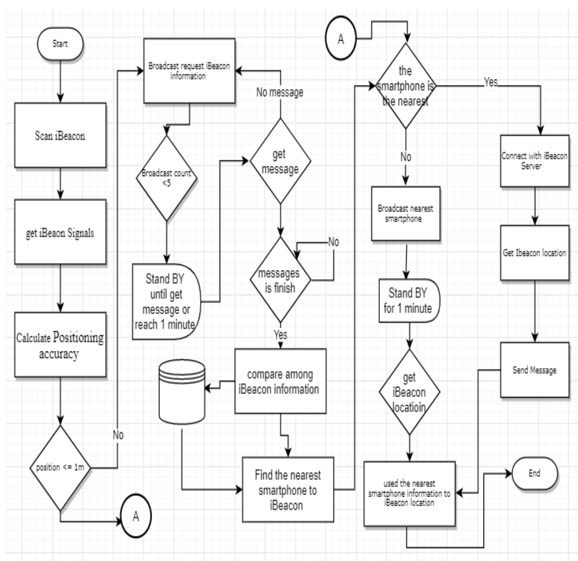

Figure 5: The UML flow chart of BHSA

The main purpose of using BHSA is to allow all the smartphones in the indoor environment to detect the iBeacon signals and estimate the distance by using TX power and RSSI information. BHSA in all smartphones which receives iBeacon signals runs the distance estimation procedures in order to determine the exact location of iBeacon, and how far the smartphone is from the iBeacon location. If the calculated distance is less than 1m from the iBeacon, then BHSA broadcasts a message that it is the nearest smartphone ("this smartphone is the nearest"), after which it connects with iBeacon server. If the calculated distance is more than 1m, then BHSA broadcasts a message with specific UUID of iBeacon, which includes smartphone ID, and its accurate position from iBeacon to other smartphones. The smartphone will be in standby position to receive signal from other smartphones (which have BHSA installed) which have received the signal and are interested in this particular iBeacon. The initial smartphone (nearest) starts receiving signal from other interested BHSA installed smartphones. Once, it receives signals from all smartphones, it compares the information and builds a database for this particular iBeacon and saves the information in it. Then, BHSA in initial smartphone (nearest) finds other nearest smartphones to the iBeacon based on the saved information, and estimates the location of other smartphones to the iBeacon. After that all other smartphones sends messages to the other close smartphones with BHSA and moves to standby for receiving the iBeacon location. The position accuracy procedure for estimating the distance id presented figure 4 below [32]:

```
protected static double calculateAccuracy(int txPower, double rssi) {

        if (rssi == 0) {
        return -1.0; // if we cannot determine accuracy, return -1.
        }
          double ratio = rssi*1.0/txPower;
          if (ratio < 1.0) {
          return Math.pow(ratio,10);
        }
        else {
              double accuracy = (0.89976)*Math.pow(ratio,7.7095) + 0.111;
              return accuracy;
        }
}
```

Figure 6. Procedure for estimating the distance id

While in standby mode, BHSA receives messages from other smartphones, compares the message information to identify other smartphones close to it. The BHSA in the smartphones again sends another message to the identified nearby smartphones, which can communicate and interested in this particular iBeacon. This process repeats, resulting in a network of smartphones with BHSA interested in a particular iBeacon. The messages from all other smartphones are communicated to the initial smartphone that has created the database, which communicate with iBeacon server to get the iBeacon location and the positioning of all other smartphones in indoor environment.

4. Conclusion

The purpose of this paper is to provide an effective solution to indoor positioning and tracking, the area in which GPS solution may not be effective. Though various technologies are available for indoor positioning and tracking, issues related to signal propagation such as obstructions (walls, furniture, people etc.) resulted in poor accuracy of indoor positioning. In order to address this issue, an effective BLE HUB solution was proposed in this paper. A network of smartphones with BHSA application is created, in which all the smartphones communicate with each other in real-time in order to identify the iBeacon location, and their accurate distance from iBeacon, which can result in high accurate positioning. The design proposed in this paper is easy to use, cost-effective, and requires little configuration settings for implementation, as the majority of the processes are handled by BHSA application. Thus, the design proposed in this paper can have major practical implications, as it can be used in various industries such as warehouse and logistics, hospitals, and many other industries which require indoor positioning and tracking. In addition, it contributes to the Bluetooth Low Energy literature by providing an effective BLE Hub design than can simplify the process of indoor positioning and achieve higher accuracies in location positioning and estimating distances.

References

[1] Dharani, M. (2013). Broadcasting Using Bluetooth Server. *International Journal of Engineering Research & Technology (IJERT), 02(04),* pp 1392-1397. broadcasting-using-bluetooth-server-IJERTV2IS4580(1).pdf

[2] Garcia, M., Martinez, C., Tomas, J., & Lloret, J. (2007, October). Wireless Sensors self-location in an Indoor WLAN environment. In *2007 International Conference on Sensor Technologies and Applications (SENSORCOMM 2007)* (pp. 146-151). IEEE.

[3] Korhonen, J., Ojala, T., Klemola, M., & Vaananen, P. (2006, February). mtag-architecture for discovering location specific mobile web services using RFID and its evaluation with two case studies. In *Advanced Int'l Conference on Telecommunications and Int'l Conference on Internet and Web Applications and Services (AICT-ICIW'06)* (pp. 191-191). IEEE.

[4] Zhao, Y., Dong, L., Wang, J., Hu, B., & Fu, Y. (2008, October). Implementing indoor positioning system via ZigBee devices. In *2008 42nd Asilomar Conference on Signals, Systems and Computers* (pp. 1867-1871). IEEE.

[5] Hussain, S. R., Mehnaz, S., Nirjon, S., & Bertino, E. (2017). Secure seamless bluetooth low energy connection migration for unmodified IoT devices. *IEEE Transactions on Mobile Computing*, *17*(4), 927-944.

[6] Dalkılıç, F., Çabuk, U. C., Arıkan, E., & Gürkan, A. (2017, October). An analysis of the positioning accuracy of iBeacon technology in indoor environments. In *2017 International Conference on Computer Science and Engineering (UBMK)* (pp. 549-553). IEEE.

[7] Paek, J., Ko, J., & Shin, H. (2016). A measurement study of BLE iBeacon and geometric adjustment scheme for indoor location-based mobile applications. *Mobile Information Systems*, *2016*.

[8] Lin, X. Y., Ho, T. W., Fang, C. C., Yen, Z. S., Yang, B. J., & Lai, F. (2015, August). A mobile indoor positioning system based on iBeacon technology. In *2015 37th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)* (pp. 4970-4973). IEEE.

[9] Zhao, Z., Fang, J., Huang, G. Q., & Zhang, M. (2016, September). iBeacon enabled indoor positioning for warehouse management. In *2016 4th international symposium on computational and business intelligence (ISCBI)* (pp. 21-26). IEEE.

[10] Wu, X., Shen, R., Fu, L., Tian, X., Liu, P., & Wang, X. (2017). iBILL: Using iBeacon and inertial sensors for accurate indoor localization in large open areas. *IEEE Access*, *5*, 14589-14599.

[11] Martin, P., Ho, B. J., Grupen, N., Muñoz, S., & Srivastava, M. (2014, November). An iBeacon primer for indoor localization: demo abstract. In *Proceedings of the 1st ACM Conference on Embedded Systems for Energy-Efficient Buildings* (pp. 190-191).

[12] He, S., Hu, T., & Chan, S. H. G. (2015, November). Contour-based trilateration for indoor fingerprinting localization. In *Proceedings of the 13th ACM Conference on Embedded Networked Sensor Systems* (pp. 225-238).

[13] Baert, M., Rossey, J., Shahid, A., & Hoebeke, J. (2018). The Bluetooth mesh standard: An overview and experimental evaluation. *Sensors*, *18*(8), 2409.

[14] Leonardi, L., Patti, G., & Bello, L. L. (2018). Multi-hop real-time communications over bluetooth low energy industrial wireless mesh networks. *IEEE Access*, *6*, 26505-26519.

[15] Zenker, P., Krug, S., Binhack, M., & Seitz, J. (2016, July). Evaluation of BLE Mesh capabilities: A case study based on CSRMesh. In *2016 Eighth International Conference on Ubiquitous and Future Networks (ICUFN)* (pp. 790-795). IEEE.

[16] Levis, P., Clausen, T., Hui, J., Gnawali, O., & Ko, J. (2011). The trickle algorithm (rfc 6206). *Internet Engineering Task Force (IETF)*, 1-13.

[17] Kim, H. S., Lee, J., & Jang, J. W. (2015, August). Blemesh: A wireless mesh network protocol for bluetooth low energy devices. In *2015 3rd International Conference on Future Internet of Things and Cloud* (pp. 558-563). IEEE.

[18] Mesh Networking Specifications. Available online: https://www.bluetooth.com/specifications/meshspecifications. (accessed on 11 July 2020).

[19] Murillo Mange, Y., Reynders, B., Chiumento, A., Malik, S., Crombez, P., & Pollin, S. (2017). Bluetooth Now or Low Energy: Should BLE Mesh Become a Flooding or Connection Oriented Network?. *IEEE PIMRC 2017 Special Session SP-04*, 2017.

[20] Darroudi, S. M., & Gomez, C. (2017). Bluetooth low energy mesh networks: A survey. Sensors, 17(7), 1467.

[21] Bluetooth SIG. Available online: https://www. bluetooth.com/ (accessed on 11 July 2020).

[22] Apple iBeacon Available online: https://developer .apple.com/ibeacon/ (accessed on 11 July 2020).

[23] Eddystone. Available online: https://developers. google.com/beacons/eddystone (accessed on 11 July 2020).

[24] AltBeacon. Available online: http://altbeacon.org/ (accessed on 11 July 2020).

[25] Herrera Vargas, M. (2016). Indoor navigation using bluetooth low energy (BLE) beacons.

[26] Pušnik, M., Galun, M., & Šumak, B. (2020). Improved Bluetooth Low Energy Sensor Detection for Indoor Localization Services. *Sensors*, *20*(8), 2336.

[27] Cantón Paterna, V., Calveras Auge, A., Paradells Aspas, J., & Perez Bullones, M. A. (2017). A bluetooth low energy indoor positioning system with channel diversity, weighted trilateration and kalman filtering. *Sensors*, *17*(12), 2927.

[28] Peter Kacandes (2016) Beacon Technology: Everything You Need to Know to Start Coding. Available online:https://dzone.com/articles/beacon-technology-everything-you-need-to-know-to-s-1. (accessed on 5 July 2020).

[29] Grzechca, D., Pelczar, P., & Chruszczyk, Ł. (2016). Analysis of object location accuracy for iBeacon technology based on the RSSI path loss model and fingerprint map. *International Journal of Electronics and Telecommunications*, *62*(4), 371-378.

[30] Zafari, F., & Papapanagiotou, I. (2015, December). Enhancing ibeacon based micro-location with particle filtering. In *2015 IEEE Global Communications Conference (GLOBECOM)* (pp. 1-7). IEEE.

[31] Ng, T. M. (2015). From "Where I am" to "Here I am": Accuracy study on location-based services with iBeacon technology. *HKIE Transactions*, *22*(1), 23-31.

[32] lizard (2019) The distance estimate iBeacon signal strength. . Available online: http://www.digipine.com/index.php?mid=macios&document_srl=28543&listStyle=viewer.