2022 8th International Engineering Conference on Sustainable Technology and Development (IEC) | 978-1-6654-7829-8/22/$31.00 ©2022 IEEE | DOI: 10.1109/IEC54822.2022.9807489

# Indoor Positioning System Based on Wi-Fi and Bluetooth Low Energy

Faeza A. Abed
*Institute of Technology*
*Middle Technical University*
Iraq, Baghdad
dr.faeza.khafaji@gmail.com

Zahraa A. Hamza
*Electrical Engineering Technical College,*
*Middle Technical University*
Iraq, Baghdad
Zahraaabbasct9@gmail.com

Mahmood F Mosleh
*Electrical Engineering Technical College,*
*Middle Technical University*
Iraq, Baghdad
drmahmoodfarhan@gmail.com

***Abstract*— With the increase in the popularity of wireless technology, almost all utilize their handset for much more than just making phone calls. One of the easy-to-implement applications is to locate objects and place them under surveillance, such as children, patients, or even valuable possessions. The idea is to exploit the possibility of routers that work with a Wi-Fi or Bluetooth signal for additional applications to perform tasks without an added cost. In this paper, a proposed model that included 3 Access Points (APs) and one target are installed in a case study room with a dimension of 8*8 m$^2$ to localize and track the target within it. The 3 APs are installed in a chosen location to apply the Trilateration algorithm in order to, detect the location of such target. Also, the APs signal is used Wi-Fi and Bluetooth to compare which one is precise. The tools used for measuring the received signal (AirPort Utility) and (Bluetooth Received Signal Strength Indicator (RSSI) Analyzer) for Wi-Fi and Bluetooth respectively. The results show that the average errors are 1.3 m and 1.7 m for Wi-Fi and Bluetooth respectively. From this result, we conclude that estimating coordinates inside the room using Wi-Fi technology is more accurate than using Bluetooth technology under the same conditions. This model can be added as an additional application to the Wi-Fi and Bluetooth devices that are available in our life.**

***Keywords*— *Wi-Fi, BLE, Indoor positioning, RSSI, Trilateration, Bluetooth***

## I. INTRODUCTION

Consumers' location capabilities have become critical in recent years [1] as a result of the proliferation of numerous services that rely on them, ranging from entertainment to personal security services and others. Wireless is used alongside the important applications of wireless technology to locate specific targets within the indoor environment. The reason for this is that Global Position System (GPS) cannot be used indoors due to the high error rate [2]. But, due to the drawbacks of indoor settings, several approaches have been created that utilize more dispersed indoor technology such as RFID, Wi-Fi, and Bluetooth [3]. Due to the widespread usage of Wi-Fi and Bluetooth Low Energy (BLE) devices with their low cost, we deployed such devices to apply our experiment [4]. A current area of study is integrating the advantages of various positioning technologies. As a consequence, the possibility of dual indoor positioning via Wi-Fi and Bluetooth is being considered. In the case of a need for less energy, BLE is used, while the Wi-Fi signal can be used if there is power available. Both included advantages and disadvantages, and each system can be used in certain circumstances that serve their conditions [5]. In 2016 Mohd Ezanee Rusli et.al. [6] Proposed an optimized RSSI-Trilateration-based system for Wi-Fi indoor localization, in which Trilateration is used to determine the target location and the result is then modified using a fixed reference point; the average error was reduced from two meters to one meter using the revised scheme. In 2018, Z. Zheng, L. Liu, L. Zhang, and Y. Fang [7]provided a system based on Bluetooth technology to achieve a low energy system to deal with many applications. This technology is considered as ranging in addition to fingerprint methods. However, there are different aspects between the mentioned methods like the position of beacons is known in contrast, the fingerprint method required a database of previous measurements that matching with real measurements to achieve final positioning. The target movements will be collected and the PDR method presented to process data. To optimize the system both fingerprint and ranging methods were implemented. The results show more stable measurements were led to fewer errors. In this research, we apply a special experiment to follow the movement of a target within a specific area, for example, following the movement of a child inside a room. The idea is to apply a proposed system that included the number of APs work as Wi-Fi or Bluetooth in order to compare the performance of each one in terms of determining the accuracy of the location. The content of this paper is structured as follows. Section two provides a survey of the related work, then, the Indoor positioning based on Wi-Fi is presented in section three. The indoor positioning based on BLE is presented in section four then the case study is presented in section five. The results and the discussion are presented in section six Finally, the conclusion is given in section seven.

## II. RELATED WORK

Given the importance of indoor positioning in the modern era, there has been a great deal of research on the topic, using wireless technologies such as Bluetooth, Wi-Fi, and RFID, as well as different methods for resolving the problem depending on the transmitters. For example, Bluetooth Triangulation[8] decides a device's location using three Bluetooth signals. Though signals and Trilateration are used to determine the unit's position, the results are accurate due to the unit's special use of Bluetooth technology. Certain systems employ only Bluetooth transmitters but employ more complex algorithms to determine the unit's direction, as in [9], where Bluetooth transmitters are scattered in a known array and the position is calculated using a previously trained neural network. Pre-training a network is not easy in most interiors; particle filtering, as proposed in [10], reduces the need for extensive prior knowledge; however, the challenge lies in filtering particles and the associated computational cost; however, the use of more advanced algorithms enables the device to be located more precisely. The technique described in [11]is interesting in that it makes use of RSSI information between several fixed wireless Beacons to boost the sensitivity of a Bluetooth positioning system and to calibrate the sensor responses. Numerous approaches, like [12, 13], employ fingerprints to estimate location. There is another approach that, given the availability of sensing devices equipped with Bluetooth, Wi-Fi, and GPS, maximizes the signal present in the indoor environment, as indicated in [14], which is based on the pre-existing RSSI Bluetooth and RSSI Wi-Fi maps, a well-established source of knowledge. Distribution of Bluetooth and other Wi-Fi stations Another fusion approach used in [15] is very fascinating due to its simplicity; it attempts to supplement these equations with force signals from an AP, which, if the number of observable satellites is less than four, completes the series of equations with Wi-Fi equations, a method close to that used in [16].

## III. Indoor Positioning Based on Wi-Fi

Local wireless networks have become commonplace as wireless and embedded infrastructure advances have fuelled the rise of the mobile industry, and convergence of wireless technologies with embedded devices such as smartphones has become popular. It's opening up a new avenue for efficient computations and networking functionality utilizing built-in sensors for a variety of pleasant applications. RSSI is a technique for determining the path in which a target device is moving. The distance between two nodes can be calculated related to the energy of the signal obtained at one end and applying a path loss model. Also, RSSI may be used to denote both a constant and a variable component. The constant component applies to models of path loss propagation, while the variable component is applicable to a number of dynamic propagation effects [17]. Signal attenuation, multipath impacts, and shadowing are also examples of propagation effects. The arrangement of such an experiment needs at least three or four reference nodes with known coordinates in order to approximate the three-dimensional (3D) location of a destination node. The transmitter sends control channels or signals from the beacon, which are received and processed by the target node. To determine the place site of such a target, the measurements of the captured and analyzed signals can be used [17]. Any radio signals suffer from a condition recognized as a shortage of available room for transmission[18]. A model of a log-normal path loss (PL(d)) can be determined by [19]:

$$PL(d) = PLo + 10\, n \log_{10}\left(\frac{d}{do}\right) + X\sigma \tag{1}$$

Where $PL_0$ is the path loss at reference distance $d_0$ (1 meter). The value can be calculated from the Friis equation or field measurements and is recommended by [18] and other research. Also, $n$ is the exponent of path loss which relies on the relevant propagation environment, and if barriers occur, the value will become greater, d is the distance between the coordinator and the mobile node in meters and $X\sigma$ is the Gaussian random variable is zero-mean (in decibels) deviation. The above parameters ($d_0$, $n$, and $X\sigma$) describe the model of path loss that has a fixed distance for receiving and transmitting. The platform is capable of being used to develop and evaluate general wireless networks.

The RSSI in dBm of the mobile node at the coordinator node can be calculated as follows [19]:

$$RSSI = P_T - PL(d) \tag{2}$$

Where $P_T$ is the transmitter's power in dBm, the RSSI at the coordinator node will be:

$$RSSI = P_T - PL_0 - 10\, n \log_{10}\left(\frac{d}{do}\right) - X\sigma \tag{3}$$

The Wi-Fi module's RSSI can be obtained from actual measurements and $X\sigma$ can be obtained from curve fitting. The distance ($d_i$) between the receiver and the AP can also be calculated according to [20]:

$$d_i = d_0\, 10^{-\left(\frac{RSSI - P_T + pl_0 + X\sigma}{10n}\right)} \tag{4}$$

In this work, the obtained value of $PL_0$ is 35 dBm (provided from the Friis equation for 2.4 GHz) [21], the path loss exponent $n$ depends on the setting and in the range of (2-6) for indoor environments, and the standard deviation $X\sigma$ can take the range of (2-14) [22].

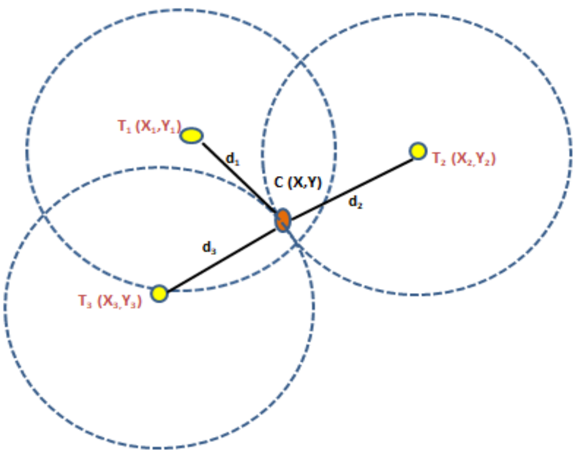


Fig. 1. Trilateration method

The main aim of the place location method is to determine the coordinates of the target node. Reference nodes must reside in the wireless coverage area of established geometrical coordination to chart measurements obtained to identify the target node location in order to approximate the unknown target node position [23].

To calculate the location of a target node in the RSSI process, the Trilateration technique is used. To approximate the location of positioning in the case of 2D, three reference nodes or more are expected. In the case of 3D, four reference nodes or more are required. Each reference node is assumed to be in the center of the circle. At the diameter of the circle lies the target node [24].

The distances $d_i$ $(i = 1, 2, 3)$ between the reference nodes and each target node must be calculated to apply the Trilateration method, using " (5)" to "(7)" [25]:

$$d_1 = d_0 \sqrt[n]{\frac{P_0}{P_1}} \tag{5}$$

$$d_2 = d_0 \sqrt[n]{\frac{P_0}{P_1}} \tag{6}$$

$$d_3 = d_0 \sqrt[n]{\frac{P_0}{P_1}} \tag{7}$$

The loss of an exponential path is defined as [23]:

$$\frac{P_r}{P_0} = \left(\frac{d_0}{d_i}\right)^n \tag{8}$$

Where $d_0$ is the distance of reference, $P_r$ is the power of the receiver, $P_0$ is the power of the receiver at a reference distance $d_0$, and n is the path loss exponent which relies on the relevant propagation environment ($n$=2 for free-space path loss).

It is possible to determine the estimated location of the target using the information derived from the circle radius describing the distance between the reference nodes and the target point. Where the number of reference nodes should be greater than or equal to three, the Coordinator of the estimated location can be calculated using the maximum likelihood estimation approach [25]. Such approximation is estimated by the convergence of three circles illustrated in Fig.1

$$X = \frac{X_2^2 + d_1^2 - d_2^2}{2 * X_2} \tag{9}$$

$$Y = \frac{X_3^2 + Y_3^2 + d_1^2 - d_3^2 - 2 * X * X_3}{2 * Y_3} \tag{10}$$

To date, several works [24-26] have been proposed to include Wi-Fi, with drastic modifications. It is feasible to use RSSI calculation of our indoor Wi-Fi points as well as the minimization of Trilateration techniques to determine the coverage radius of the building.

## IV. Indoor Positioning Based on BLE

BLE is a personal area network technology that uses short-range radios to facilitate data transfers. Since it is inexpensive and energy-efficient, Classic Bluetooth's distance limitations apply it is perfect for tasks that include transferring small amounts of data over short periods. Bluetooth is more often used for more general networking applications that need a secure connection and more data transfer. To determine the location of the target based on BLE, a three-borders method can be used in this work. As shown in Fig. 2, the directions of reference hubs $C_1$, $C_2$, and $C_3$ are $(X_1, Y_1)$, $(X_2, Y_2)$, and $(X_3, Y_3)$ and the distances between these hubs to the portable are $d_1$, $d_2$, and $d_3$. Assume that directions of the portable are (X, Y), can be calculated using "(11)" to "(13)" [27]:

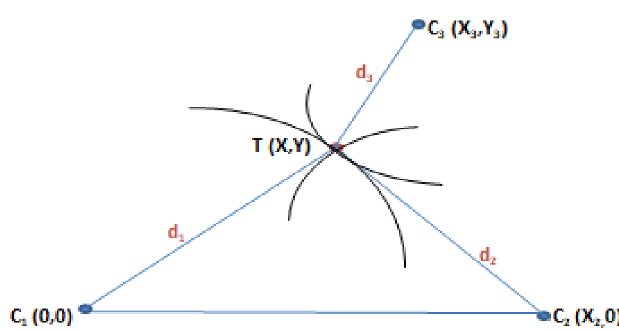


Fig. 2. Positioning on three borders.

$$d_1^{\,2} = (X - X_1)^2 + (Y - Y_1)^2 \qquad (11)$$

$$d_2^{\,2} = (X - X_2)^2 + (Y - Y_2)^2 \qquad (12)$$

$$d_3^{\,2} = (X - X_3)^2 + (Y - Y_3)^2 \qquad (13)$$

By addressing the condition of the three borders method, we can get the plan of the versatile. The target point *T* coordinates are (X, Y), the first reference point coordinates are (0, 0), the second reference point coordinates are ($X_2$, 0), and the third reference point coordinates are ( $X_3$, $Y_3$). Then we can extract the coordinates through an "(9)" and " (10)" .

## V.The case study

A case study of (8*8 $m^2$) room is chosen to apply our experiment which is based on Line-of-Sight (LoS) environment because of limited space. The idea is to track the movements of children or any patient person within such room and transmit the information about such movement wirelessly to the user. Also, we used each Wi-Fi and Bluetooth and got the result of each one individually in order to compare between them in terms of accuracy. To measure RSSI, we utilized the IOS system to sit the required program such (AirPort Utility) and (Bluetooth RSSI Analyser) for Wi-Fi and Bluetooth respectively. The procedure of applying our proposal explained is as follows:

- Install 3 APs in three places including Wi-Fi and Bluetooth system. The coordinates $AP_1$, $AP_2$, and $AP_3$ (0.5, 4), (7.5, 7.5) , and (8, 1) respectively as shown in Fig. 3. Note that the Bluetooth worked with low energy which we expect can be continued for long period with low power consumption which differs from Wi-Fi devices.
- Measure the RSSI by Wi-Fi and Bluetooth under the same condition for measurement for each Wi-Fi and Bluetooth.
- According to "(9)" and "(10)" the coordinate of a target will be estimated for Wi-Fi and Bluetooth measurement.
- A comparison will be applied to show the accuracy of target setting

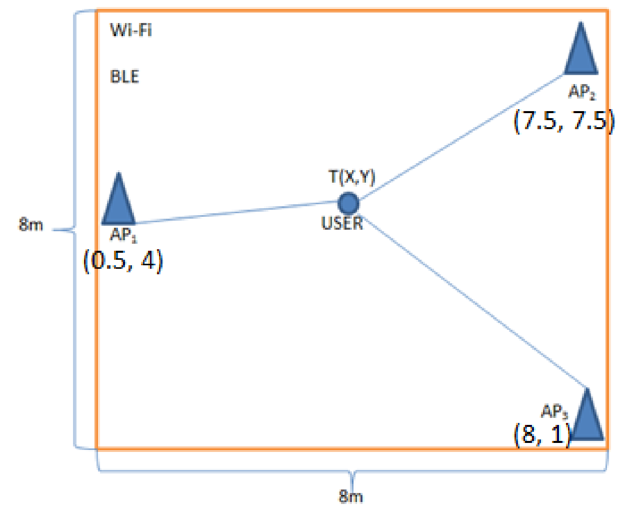


Fig. 3. Departmental indoor environment for Wi-Fi and Bluetooth Low Energy research purposes.

## VI.Results and the Discussion

In this research the result of each device is got individually to evaluate their performance clearly as follow:

*A. For Wi-Fi Technology: a ten reading of RSSI is* measured for each AP (10 seconds between each reading). The result of 30 readings (10 for each AP) is listed in Table I. To obtain a better result, we choose the value which has more account than others for example -45 dBm has more frequent than others for $AP_1$. Also, -53 dBm and -66 dBm are more frequent for $AP_2$, $AP_3$ respectively. Note that, the expected values of RSSI must be not less than -120 dBm according to [28].

Table I. The result of RSSI Wi-Fi

| Wi-Fi | RSSI (dBm) | More Frequent (dBm) |
|---|---|---|
| $AP_1$ | -44,-45,-45,-46,-45,-43,-45,-47,-49,-46 | -45 |
| $AP_2$ | -55,-53,-53,-54,-53,-52,-53,-59,-56,-53 | -53 |
| $AP_3$ | -65,-66,-66,-64,-62,-65,-66,-66,-69,-66 | -66 |

By applying the procedure of section V to estimate the target position and calculate the error between the real and estimated position as follow:

- Read ten values for each access point and choose the frequent one. from Table I the RSSI of $AP_1$, $AP_2$, and $AP_3$ are -45 dBm,-53 dBm, and -66 dBm respectively
- Estimate the position according to "(9)" and "(10)" which illustrate that estimated position (3.2333, 4.131).
- The value of error is 1.3 *m*.

*B. For BLE technology:* ten readings of RSSI are measured for each AP (10 seconds between each reading). The result of 30 readings (10 for each AP) is listed in Table II. To obtain a better result, we choose the value which has more account than others for example -70 dBm has more frequent than others for $AP_1$. Also, -80 dBm and -79 dBm are more frequent for $AP_2$, $AP_3$ respectively.

TABLE II: THE RESULT OF RSSI BLE

| BLE | RSSI (dBm) | More Frequent (dBm) |
|---|---|---|
| $AP_1$ | -70,-69,-70,-70,-71,-73,-70,-72,-69,-70 | -70 |
| $AP_2$ | -79,-80,-80,-80,-78,-81,-83,-80,-80,-79 | -80 |
| $AP_3$ | -78,-79,-79,-80,-78,-81,-79,-79,-80,-79 | -79 |

By applying the procedure of section V to estimate the target position and calculate the error between the real and estimated position as follow:

- Read ten values for each access point and choose the frequent one. from Table II the RSSI of AP1, AP2, and AP3 are -70 dBm,-80 dBm, and -79 dBm respectively
- Estimate the position according to "(9)" and "(10)" which illustrate that estimated position (4.427932, 2.811582).
- The value of error is 1.7 m.

It's noteworthy that previous work such as [29] who is applied an experimented of positioning using Wi-Fi within indoor environments how to achieve an average error is 5.5 *m* for 6 APs while the current research got an error is 1.3 *m* In addition, the author of [30] who deploy the Bluetooth system for the same goal and achieved localization precision of 3 *m* while the current research got an error is 1.7 *m*.

The proposed model can be extended to apply the tracking capability. In the case of there being a clear difference in determining the two consecutive locations, this means that the object has moved from its place for a distance equal to the difference between the two readings. At that time, an alert can be sent to the user that there is a clear change in the body that is under observation. Also, because of the availability of Wi-Fi devices in all homes and the Bluetooth system with our phones, the proposed system will take important in practical applications to serve those how need to monitor or track moving objects such as babies, patients, and animals.

## VII. CONCLUSIONS

In this research, a proposed model used to estimate the location and track any object is evaluated. Such a model uses each Wi-Fi and BLE in order to compare between them and to offer more flexibility in terms of power availability. The result shows that the estimated positioning can be applied with an average of error 1.3 *m* and 1.7 *m* for Wi-Fi and BLE respectively. From this result, we conclude that estimating coordinates inside the room using Wi-Fi technology is more accurate than using Bluetooth technology under the same conditions. The estimation can be repeated in a regular period and in case of a significant difference between two consecutive readings, an alarm can be sent to the user.

## ACKNOWLEDGMENT

I would like to earnestly acknowledge the sincere efforts and valuable time given by my teacher. His valuable guidance and feedback have helped me in completing this project.

## References

[1] Su, H.-K., et al. A hybrid indoor-position mechanism based on Bluetooth and WiFi communications for smart mobile devices. in 2015 International Symposium on Bioelectronics and Bioinformatics (ISBB). 2015. IEEE.

[2] A. Baniukevic, C.S. Jensen, and H. Lu. Hybrid indoor positioning with wi-fi and Bluetooth: Architecture and performance. in 2013 IEEE 14Th international conference on mobile data management. 2013. IEEE

[3] L. Batistić, and M. Tomic. Overview of indoor positioning system technologies. in 2018 41st International Convention on Information and Communication Technology, Electronics, and Microelectronics (MIPRO). 2018. IEEE.

[4] G.M. Mendoza-Silva, J. Torres-Sospedra, and J. Huerta, A meta-review of indoor positioning systems. Sensors, 2019. 19(20): p. 4507.

[5] K. Kim, et al., Feasibility of LoRa for Smart Home Indoor Localization. Applied Sciences, 2021. 11(1): p. 415.

[6] J.H Huh, and K. Seo, An indoor location-based control system using Bluetooth beacons for IoT systems. Sensors, 2017. 17(12): p. 2917.

[7] M..E. Rusli, et al. An improved indoor positioning algorithm based on RSSI-trilateration technique for the internet of things (IoT). in 2016 International Conference on Computer and Communication Engineering (ICCCE). 2016. IEEE.

[8] Z. Zuo, et al., Indoor positioning based on Bluetooth low-energy beacons adopting graph optimization. Sensors, 2018. 18(11): p. 3736.

[9] F.S. Daniş, and A.T. Cemgil, Model-based localization and tracking using Bluetooth low-energy beacons. Sensors, 2017. 17(11): p. 2484.

[10] S. He, and S.-H.G. Chan, Wi-Fi fingerprint-based indoor positioning: Recent advances and comparisons. IEEE Communications Surveys & Tutorials, 2015. 18(1): p. 466-490

[11] V. Bianchi, , P. Ciampolini, and I. De Munari, RSSI-based indoor localization and identification for ZigBee wireless sensor networks in smart homes. IEEE Transactions on Instrumentation and Measurement, 2018. 68(2): p. 566-575.

[12] P. Davidson, and R. Piché, A survey of selected indoor positioning methods for smartphones. IEEE Communications Surveys & Tutorials, 2016. 19(2): p. 1347-1370.

[13] O. Belmonte-Fernández, et al., A Generative Method for Indoor Localization Using Wi-Fi Fingerprinting. Sensors, 2021. 21(7): p. 2392.

[14] A. Yassin, et al., Recent advances in indoor localization: A survey on theoretical approaches and applications. IEEE Communications Surveys & Tutorials, 2016. 19(2): p. 1327-1346.

[15] R. Challoo, et al., An overview and assessment of wireless technologies and co-existence of ZigBee, Bluetooth, and Wi-Fi devices. Procedia Computer Science, 2012. 12: p. 386-391.

[16] A.C.-C. Hsu, , D.S. Wei, and C.-C.J. Kuo, Coexistence wi-fi MAC design for mitigating interference caused by collocated Bluetooth. IEEE Transactions on Computers, 2013. 64(2): p. 342-352.

[17] J.I Huircán,., et al., ZigBee-based wireless sensor network localization for cattle monitoring in grazing fields. Computers and Electronics in Agriculture, 2010. 74(2): p. 258-264.

[18] S. Savazzi, , et al., A Bayesian approach to device-free localization: Modeling and experimental assessment. IEEE Journal of Selected Topics in Signal Processing, 2013. 8(1): p. 16-29.

[19] F. Fuschini, et al., Ray tracing propagation modeling for future small-cell and indoor applications: A review of current techniques. Radio Science, 2015. 50(6): p. 469-485.

[20] T.S. Rappaport., et al., Wideband millimeter-wave propagation measurements and channel models for future wireless communication

system design. IEEE transactions on Communications, 2015. 63(9): p. 3029-3056.

[21] S.L. Mohammed, , Distance estimation based on RSSI and log-normal shadowing models for ZigBee wireless sensor network. Engineering and Technology Journal, 2016. 34(15): p. 2950-2959.

[22] O.G. Adewumi, K. Djouani, and A.M. Kurien. RSSI-based indoor and outdoor distance estimation for localization in WSN. in 2013 IEEE international conference on Industrial technology (ICIT). 2013. IEEE.

[23] P. Singh, et al., Optimized localization of target nodes using single mobile anchor node in wireless sensor network. AEU-International Journal of Electronics and Communications, 2018. 91: p. 55-65.

[24] Wu, C., et al., WILL: Wireless indoor localization without site survey. IEEE Transactions on Parallel and Distributed Systems, 2012. 24(4): p. 839-848.

[25] P. Prasithsangaree, P. Krishnamurthy, and P. Chrysanthis. On indoor position location with wireless LANs. in The 13th IEEE international symposium on personal, indoor, and mobile radio communications. 2002. IEEE.

[26] Z. Farid , R. Nordin, and M. Ismail, Recent advances in wireless indoor localization techniques and system. Journal of Computer Networks and Communications, 2013. 2013.

[27] Liu, Y., et al., Location, localization, and localizability. Journal of computer science and technology, 2010. 25(2): p. 274-297.

[28] G. Çaliş , B. Becerik-Gerber, and A.B. Göktepe, Analysis of the variability of RSSI values for active RFID-based indoor applications. Turkish Journal of Engineering and Environmental Sciences, 2013. 37(2): p. 186-210.

[29] M. Abd Elgwad, ; Sheta, Bassem I. Wi-Fi based indoor localization using trilateration and fingerprinting methods. In: *IOP Conference Series: Materials Science and Engineering*. IOP Publishing, 2019. p. 012072.

[30] U.M. Qureshi, et al. Analysis of bluetooth low energy (ble) based indoor localization system with multiple transmission power levels. In: *2018 IEEE 27th International Symposium on Industrial Electronics (ISIE)*. IEEE, 2018. p. 1302-1307.

[31]