Jurnal Ilmiah Teknik Elektro Komputer dan Informatika (JITEKI)
Vol. 8, No. 1, March 2022, pp. 144-156
ISSN: 2338-3070, DOI: 10.26555/jiteki.v8i1.23697

Development of Proximity-Based COVID-19 Contact Tracing System Devices for Locally Virus Spread Prevention

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ARTICLE INFO

Article history:

Received March 25, 2022
Revised April 16, 2022
Accepted May 19, 2022

Keywords:

Beacon;
Bluetooth;
Covid-19;
Contact tracing;
Proximity;
Health care

ABSTRACT

COVID-19 contact tracing is a preventive solution to slow the spread of the virus. Several countries have implemented manual contact tracing as well as digital tracking using smartphone applications. A proximity-based COVID-19 contact tracing system device using BLE (Bluetooth Low Energy) technology focuses on tracking and controlling the spread of the virus in local communities. The devices consist of a signal sending device (tag) and a signal receiving device (scanner). Suppose a system device is implemented in a factory. The tag will be used by employees by placing it in the front pocket of the factory employee's clothes or hooked on the shirt. The tag will continuously send a signal that will be read by the scanner. This received signal with the received signal strength indicator (RSSI) format will be used to calculate the distance between the scanner and the tag. Then the distance will be used to determine the coordinate point of the tag, with calculations using the trilateration algorithm. Therefore, the distance between tags can be obtained, while with signal fluctuation, the actual coordinate point cannot be obtained, yet proximity information can still be obtained by filtering distance data at a specified time interval that is less than the threshold value of the distance, 2 meters, then comparing the data with the overall data, resulting in a percentage value. A high percentage, above 80%, indicates the closeness between tags.

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1 INTRODUCTION

Contact tracing is the process of identifying, investigating, and managing people exposed to a virus to prevent further spread. If this process can be carried out systematically, contact tracing can break the chain of disease spread and become an important tool for public health to control disease outbreaks. Contact tracing for COVID-19 disease identify people who have been or might be infected with COVID-19 based on interactions with confirmed COVID-19 people and monitors patients for the next 14 days [1]. COVID-19, or coronavirus disease, is an infectious disease caused by the SARS-CoV-2 virus. The disease can spread from person to person through droplets that come out of the mouth or nose that are emitted from people with COVID-19 disease when sneezing, coughing, or talking, and from droplets that hit an object and are touched by humans and then through their hands the virus enters the body [2].

The proximity tracing tool is one of the tools categorized by WHO to find and trace the movements of individuals to identify the possibility of a group of people who are exposed to the virus from an infected person [3]. The contact tracing tools have been widely developed to identify COVID-19 cases, including using Bluetooth signals from smartphones to collect proximity information from smartphone users to one another. Information will be obtained centrally by the government or the agency authorized to implement the application. For example, the *TraceTogether* application, which was developed and implemented by the

Singapore government [4][5] and *PeduliLindungi* by the Indonesian government [6], as well as other research-based on Bluetooth Low Energy (BLE) in smartphones with improvements in terms of overcoming privacy and mechanisms for determining various contacts [7].

This research is a continuation of preliminary research that proposes an alternative to contact tracing in local communities by using proximity-based system devices that use BLE and beacons. System devices are installed in the monitoring area so that control can be carried out independently (not centralized), and information can be obtained and processed quickly by the party responsible for the installation of the system devices [8]. This solution is to implement contact tracing without using a smartphone and address the privacy issues that are a concern of implementing contact tracing tools on smartphones [9].

The research contribution is to provide an alternative system for COVID-19 contact tracing tool which can be applied in the local community or monitoring area and to explore the ever-evolving Bluetooth technology and IoT (Internet of Things) applications that are highly relevant to today's technological conditions.

2 METHOD

This research was carried out in several stages of the process, namely devices and simulation scenario development, measurement, setting, and experimentation. The process stages and parameters, both required and generated by the system device, are illustrated in Fig. 1.

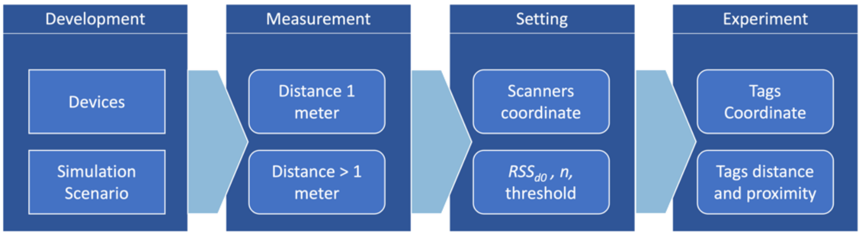


Fig. 1. Research method

The development of devices and simulation scenarios is the first thing to do to prepare prototype devices for the measurement and experiment process. Measurements were made to determine the constant values to be used for the experimental process. The first constant value was obtained from the result of the scanner and tad measurement at 1 meter. The second constant value was obtained from the result of measuring distances > 1 meter. Settings are made to place the scanner in a room or monitoring area and record all the coordinates of the scanners. Experiments were carried out to calculate the coordinates of the tags in the room, calculate the distance between the tags and determine the proximity between tags.

2.1 Devices Development

Location-based BLE [10] and beacons [11] are widely applied to indoor positioning systems (IPS). An experiment to determine the distance between BLE tags and smartphone states that using a BLE device is more accurate than Wi-Fi [12], and several experiments use both Wi-FI and BLE to provide IPS [13], [14]. Many studies utilize the transmission signal strength, RSSI, emitted by a beacon or BLE device placed at several locations or points in the monitoring area, and the signal from the beacon is received by a mobile device (smartphone) to indicate the position of the mobile device. Several algorithms are used to determine the position, such as fingerprint [15]–[18], triangulation [19]–[21], pedestrian dead reckoning (PDR) [22]–[24], trilateration or multi-lateration [25]–[35], and artificial intelligence (AI) [36]–[38], as well as by combining AI with fingerprint [39]–[42], trilateration and fingerprint [43], [44], and fingerprint and PDR [45].

What distinguishes this research from previous studies is the use of beacon devices on moving objects and the placement of other BLE devices to receive signals from beacon devices at several locations or points in the monitoring area and perform calculations to determine the proximity of the beacon devices. However, a similar approach has been performed by [43] to localize a person in the house and by [32] doing an experiment using a BLE device as tracking for IPS.

The proximity-based COVID-19 contact tracing system aims to detect the interaction of a group of people in a closed room by calculating the distance and duration of the interaction between them. The devices consist of signal sending devices (tags) and signal to receive devices (scanners). Suppose a system device is implemented in a factory. The tags will be used by employees by placing them in the front pocket of the factory employee's clothes or hooked on the shirt. Tags use a coin battery to supply the power needed to transmit the transmission signal, and the tags are compactly designed for easy wear by the user. Scanners are devices that will be installed in the monitoring area. Scanners are also designed to be compact, so they are easy to install and connect to a power source. The scanners serve to capture the signal emitted by the tags.

The scanners and tags that were developed for the measurement and experiment process are in the form of prototypes, where the scanners are made using the ESP32 [46] system on chip (SoC) [47], and the tags use the nRF51822 SoC. The ESP32 is a low-cost and powerful SoC with Wi-Fi capability and dual Bluetooth modes (Classic Bluetooth and BLE). The ESP32 is integrated with an internal antenna switch, RF balun, power amplifier, low noise amplifier, filter, and power management module. ESP32 is engineered for mobile devices, wearable electronic devices, and IoT applications. ESP32 can achieve very low power consumption through power-saving features [48] that have been widely used for Internet of Things (IoT) applications [49]–[52]. In comparison, nRF51822 [53] is a commonly used very low power SoC suitable for BLE and 2.4 GHz wireless applications, such as beacons.

Scanners are designed to be able to receive transmission signals from multiple tags at the same time as other scanners. The tag is designed to continuously transmit a signal with on/off control to turn the device on and off. The communication between the scanner and the tag uses the OASIS messaging standard protocol (open collaboration standard) for the IoT, Message Queue Telemetry Transport (MQTT) [54]. MQTT is designed as a lightweight messaging, publish/subscribe transport, making it suitable for connecting wireless devices with small memory and minimal network bandwidth.

In the communication processes via the MQTT protocol, tags act as publishers and scanners as subscribers, as shown in Fig. 2. The tags transmit the signal strength, RSSI, which is published to the Scanner ID topic and sent to MQTT Broker. MQTT Broker transmits the signal to the scanners. MQTT broker is a server that is set up for the communication process. Before communicating, the scanners must first be registered by registering the MAC address of the devices to the broker server (MQTT broker) and setting the local network key (Wi-Fi) to communicate wirelessly.

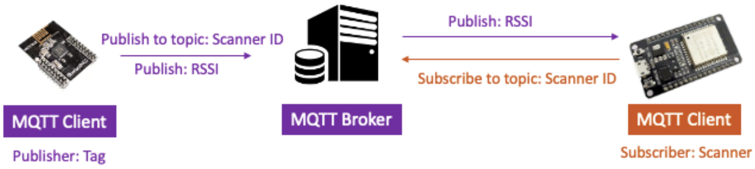
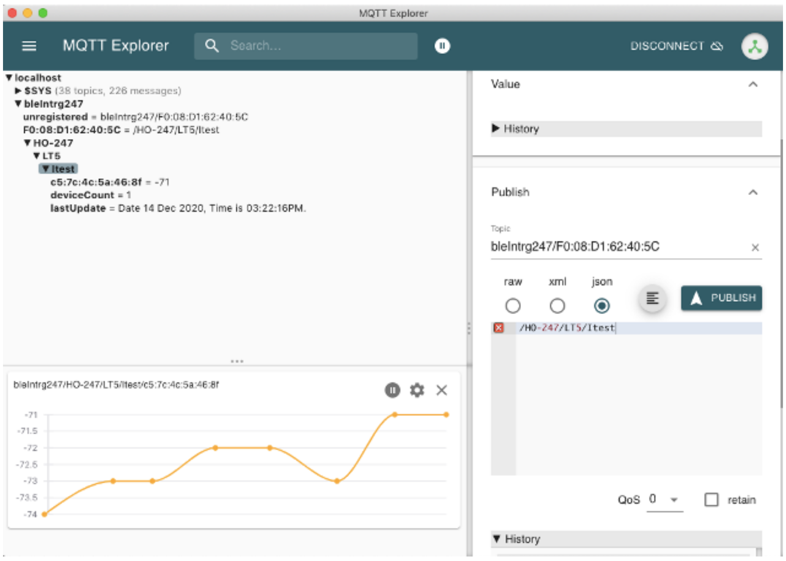


Fig. 2. Scanner and tag communication via MQTT protocol.

MQTT Explorer is a tool that can be used to view scanners that have been registered to the IP broker server and to register the scanners to receive signals from tags. In Fig. 3, the MQTT Explorer shows that a registered Scanner ID can capture the tag transmission signal and display the results of the signal measurement. In the picture, the test Scanner ID can capture the transmission signal from one tag at a time.



```
▼ localhost
  ▶ $SYS (38 topics, 226 messages)
  ▼ bleIntrg247
    unregistered = bleIntrg247/F0:08:D1:62:40:5C
    F0:08:D1:62:40:5C = /HO-247/LT5/Itest
    ▼ HO-247
      ▼ LT5
        ▼ Itest
          c5:7c:4c:5a:46:8f = -71
          deviceCount = 1
          lastUpdate = Date 14 Dec 2020, Time is 03:22:16PM.
```

Topic: bleIntrg247/F0:08:D1:62:40:5C

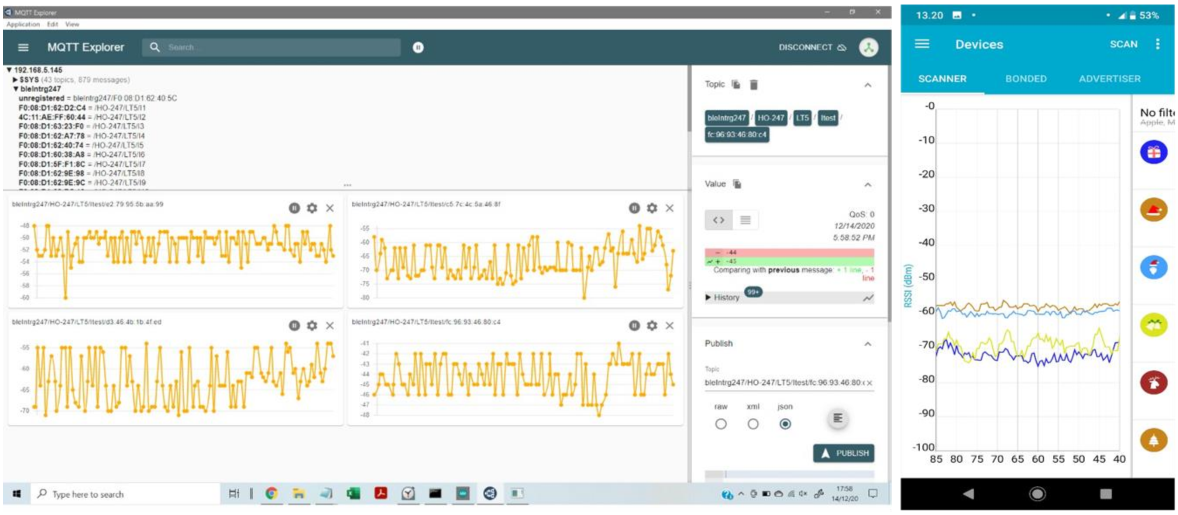
○ raw ○ xml ● json

```
/HO-247/LT5/Itest
```

bleIntrg247/HO-247/LT5/Itest/c5:7c:4c:5a:46:8f

Fig. 3. MQTT Explorer for scanner MAC address (publish) registration and monitoring

Fig. 4 shows the transmission signal of four tags received by one scanner at the same time continuously displayed in the visualization of MQTT Explorer and the BLE scanner application on the smartphone.



```
▼ 192.168.5.145
  ▶ $SYS (43 topics, 879 messages)
  ▼ bleIntrg247
    unregistered = bleIntrg247/F0:08:D1:62:40:5C
    F0:08:D1:62:D2:C4 = /HO-247/LT5/I1
    4C:11:AE:FF:60:44 = /HO-247/LT5/I2
    F0:08:D1:63:23:F0 = /HO-247/LT5/I3
    F0:08:D1:62:A7:78 = /HO-247/LT5/I4
    F0:08:D1:62:40:74 = /HO-247/LT5/I5
    F0:08:D1:60:38:A8 = /HO-247/LT5/I6
    F0:08:D1:5F:F1:8C = /HO-247/LT5/I7
    F0:08:D1:62:9E:98 = /HO-247/LT5/I8
    F0:08:D1:62:9E:9C = /HO-247/LT5/I9
```

Fig. 4. The transmission signal of four tags is received and visualized using MQTT Explorer (left) and BLE scanner apps (right)

Four tags are tested to ensure that the devices can transmit a measurable signal, and then the scanner can receive signals from all tags at the same time. BLE scanner apps from a smartphone are also used to test receiving transmission signals from tags. The transmission signal strength can be different for each tag. It is better to calibrate both from the tag and scanner side.

2.2 Simulation Scenario

A simulation scenario is a program that is used to perform a measurement to obtain constant values, RSS_{d0} and the exponent (n) of propagation model of signal transmission, and experiment. The experiment uses constant parameter values both from the measurement results and standard values from the results of previous studies to obtain proximity values between tags.

Fig. 5 shows the processes that exist in the research simulation scenario, where data from scanners and tags are the input to the simulation processes. Transmission signal data is stored on the broker server in the form of a flat-file containing signal strength information (in dBm), scanner ID, tag ID, and transmission time. The simulation consists of measurement and experimentation. Measurements produce constant RSS_{d0} and exponent (n) values for use during experimentation. The experiment performs calculations to obtain the proximity between tags. With this simulation system, the measurement and experiment process can be repeated as needed.

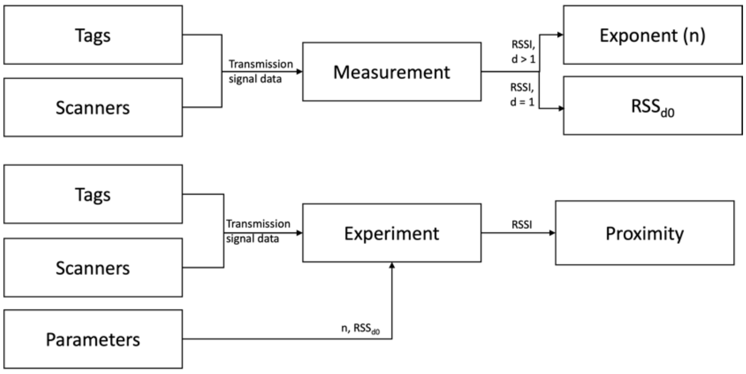


Fig. 5. Simulation scenario for measurement and experiment

2.3 Measurement

Measurement is carried out to determine the propagation model of the signal emitted by the tags. The emitted signal will be received by scanners, and its strength is measured to produce the RSSI value.

Measurements need to be made because SoCs can have different signal strengths depending on the standards of each manufacturer. The measurements taken are to check the constant RSSI value (RSS_{d0}) at 1 meter, based on the path loss model formula [55], [56]:

$$RSSI = RSS_{d_0} - 10n\log_{10}\left(\frac{d}{d_0}\right) + X_\sigma \tag{1}$$

where RSS_{d0} is the RSSI reference value measured at a specified distance d_0 at 1 meter to the signal sender. Parameter n shows the increase in path loss related to the distance, which is affected by the environmental conditions of the monitored area. The standard value is n = 2 for obstacle-free area conditions [34]. And measurements at >1 meter are also carried out to determine the propagation model of the transmission signal and calculate the average path loss exponent (n) to be compared with the standard value of n. Fig. 6 shows the position of the tag and scanner set as measured by placing the scanner on a wall and the tag on a pole parallel to the scanner position.

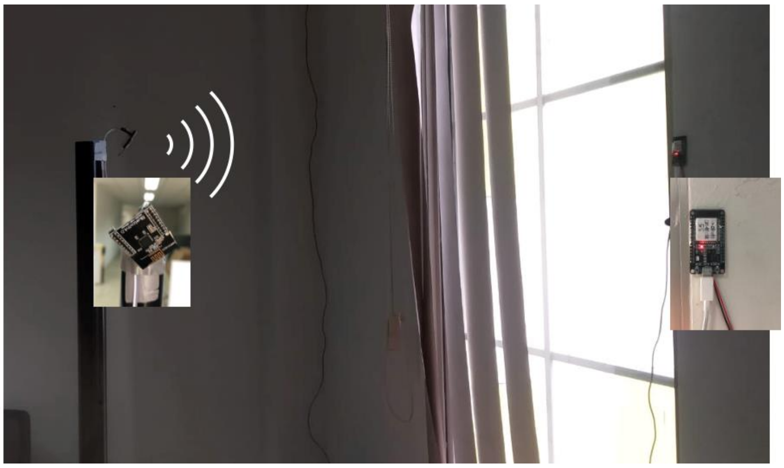


Fig. 6. Tag (left) signal transmission received by a scanner (right) measurement

Measurements are made by placing the scanner and tag at the same height without any obstructions between them. The scanner antenna is positioned facing the tag and vice versa, but there is still the possibility of the tag position shifting from the initial position. The position of the tag is shifted from 1 meter to 10 meters per 1-meter distance.

The first measurement was carried out three times for approximately 5 minutes with 1 meter between the scanner and the tag. The propagation model was obtained as shown in Fig. 7.

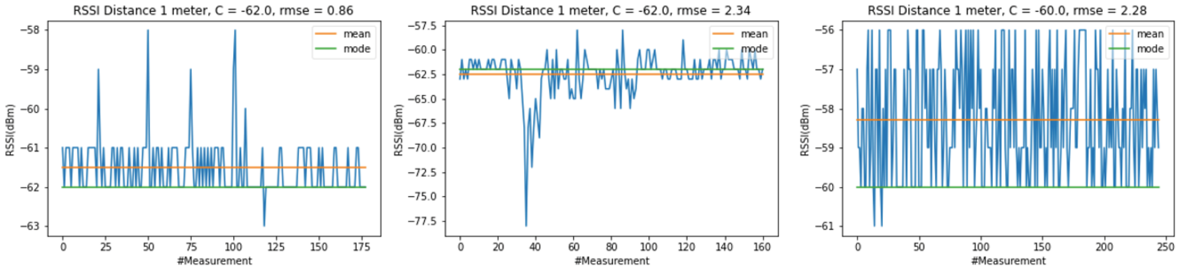


Fig. 7. RSSI measurement for distance 1 meter

The resulting propagation model is different for every 1-meter distance measurement, but a constant value of RSS_{d0} (C in Fig. 7 and Fig. 8) is obtained in the range of -60 and -62 dBm as a result of the statistical value of RSSI mode in the experimental time range, the statistical value of the mode is used to overcome the fluctuating factor of the signal [57].

The second measurement is carried out for 2 to 10 meters using the RSS_{d0} = -60 and -62 values and obtained a fluctuating RSSI value, where the fluctuating level is large at 8, 9, and 10 meters, as shown in Figure 8. It is a consideration to place at least 3 scanners within a radius of < 8 meters to generate tag coordinates in the monitoring area.

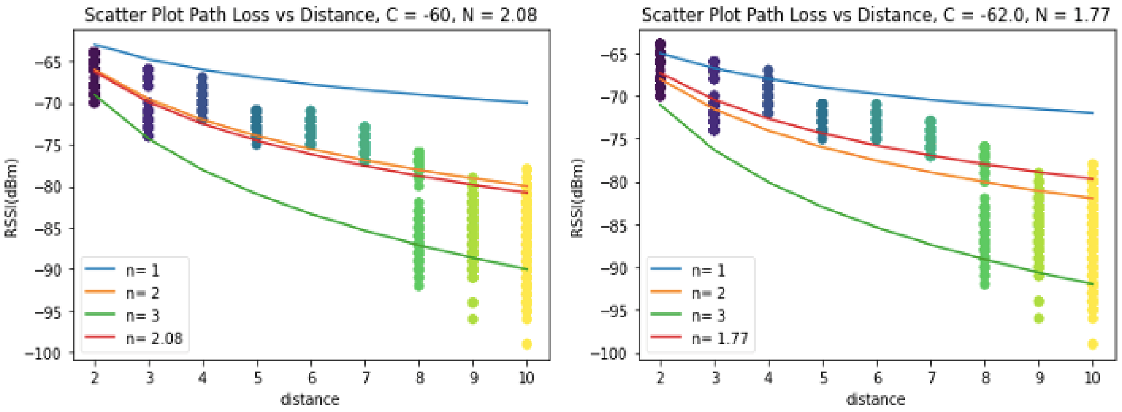


Fig. 8. RSSI measurement for distance > 1 meter (2 – 10 meters)

The exponent (n) value is obtained by entering the RSSI and RSS_{d0} values into equation (1) by averaging the n values resulting from the calculation of each RSSI. From Fig. 8 the value on n = 2.08, the result of calculation using RSS_{d0} = -60, and n = 1.77, result of calculation using RSS_{d0} = -62, are in the middle of the signal propagation model. It can be concluded that the constant values are representative enough to be used in the path loss model to find the distance.

Table 1 shows the RSS_{d0} and exponent values from measurements that will be used for the experiment, along with the standard value.

Table 1. RSS_{d0} and exponent values for experiment

No	RSS_{d0}	n (Path Loss Exponent)	Description
1	-60	2	Standard value
2	-62	1.77	Measurement value

RSS_{d0} -62 was chosen because of the three experiments carried out. Two trials yielded this value. The exponent (n) 1.77 is from the results of calculations that have been described before.

2.4 Setting

Preparation before doing an experiment is to place scanners in a position that can reach the tracking in the monitoring area. The scanner device uses BLE technology, where basically, the BLE specification does not limit the number of connections between both peripheral and central devices [58]. The scanner, in this case, functions as a peripheral device that reads transmissions from many tag devices, and the tag as a center that can transmit signals that can be read by all scanners within a maximum BLE signal range of 10-50 meters [59]. In this study, the signal range is limited to only up to 10 meters according to the measurements made.

This experiment uses 10 scanners placed in the monitoring area as seen in Fig. 9 (left), where *scanners* are placed on the ceiling of the room as seen in Fig. 9 (right), approximately 2.6 meters high, experiment by [15] concluding that high BLE beacons can reduce errors in localization results. The monitoring area is an office area consisting of bulkheads, tables, and chairs. Once the scanner is positioned, the coordinates of each scanner are calculated by specifying one point from the corner of the room as a coordinate (0.0). Table 2 shows the coordinate point of each scanner in the room. Table 3 shows the distance between scanners that is not more than 8 meters.

The line in the room on the picture shows a partition, a light blue rectangle showing the workbench area. The propagation of scanners is done randomly based on the estimate that for each point coordinate in the room if placed a tag, the transmission signal will be readable by at least 3 scanners. The estimate is determined from the results of measurements, where signal fluctuations are smaller at a distance of < 8 meters.

Coordinate scanners are calculated from the bottom corner to the left of the monitoring area in Fig. 9 as a coordinate axis by taking measurements manually in the room.

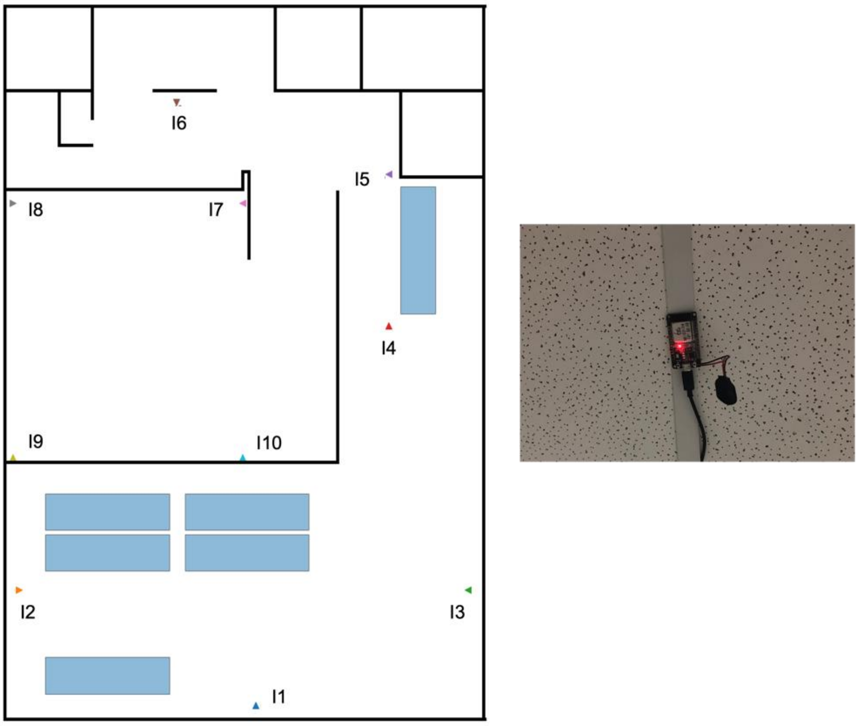


Fig. 9. Placement of scanners in the monitoring area (left) The scanner on the ceiling (right).

Table 2. Scanners Coordinate

Scanner ID	Coordinate
I1	(5.70, 0.35)
I2	(0.35, 2.89)
I3	(10.50, 2.88)
I4	(8.71, 8.69)
I5	(8.71, 12.03)
I6	(3.91, 13.74)
I7	(5.4, 11.39)
I8	(0.21, 11.39)
I9	(0.21, 5.79)
I10	(5.4, 5.79)

The distance between scanners can be calculated from the coordinates of the scanner that have been known before. The experiment calculations will only take into account the tag signal received by the scanner at a distance of < 8 meters between the scanner and the tag. This is because, at a distance of 8 meters and above, the fluctuations of the transmission signal are very unstable and irrelevant to measurements at a distance of < 8 meters. The calculation of the distance between scanners is carried out to find out whether the minimum combination of three scanners as a reference can be fulfilled. As seen in Table 3, the minimum combination of three scanners is met.

2.5 Experiment

The method of calculating point coordinates uses multilateration to predict the location of tags. Using more references (number of scanners) can improve accuracy because the weight of the error generated by each reference point will be reduced. Suppose that n reference points (total scanners that receive a signal from a tag) are used.

Table 3. Distance Between Scanners

Scanner ID 1	Scanner ID 2	Coordinate
I1	I2	5.922339
I1	I3	5.425947
I1	I9	7.728758
I1	I10	5.448266
I2	I9	2.903377
I2	I10	5.823444
I3	I4	6.07949
I3	I10	5.871806
I4	I5	3.34
I4	I6	6.967245
I4	I7	4.271545
I4	I10	4.400693
I5	I6	5.095498
I5	I7	3.371305
I5	I10	7.063547
I6	I7	2.782553
I6	I8	4.383207
I7	I8	5.19
I7	I9	7.635188
I7	I10	5.6
I8	I9	5.6
I8	I10	7.635188
I9	I10	5.19

The equation of the system will be [34]:

$$\begin{gathered} d_1 = (x - x_1)^2 + (y - y_1)^2 \\ \vdots \\ d_n = (x - x_n)^2 + (y - y_n)^2 \end{gathered} \tag{2}$$

where d is the distance between scanner and tag, (x, y) is tag coordinated and (x_1, y_1) ... (x_n, y_n) are scanners coordinate. By subtracting one by one the last equation from the other equations, the equations of the system can be linearized to:

$$Ax = b \tag{3}$$

where:

$$A = \begin{bmatrix} 2(x_1 - x_n) & 2(y_1 - y_n) \\ \vdots & \vdots \\ 2(x_{n-1} - x_n) & 2(y_{n-1} - y_n) \end{bmatrix} \tag{4}$$

$$x = \begin{bmatrix} \hat{x} \\ \hat{y} \end{bmatrix} \tag{5}$$

$$b = \begin{bmatrix} x_1^2 - x_n^2 + y_1^2 - y_n^2 + d_n^2 - d_1^2 \\ \vdots \\ x_{n-1}^2 - x_n^2 + y_{n-1}^2 - y_n^2 + d_n^2 - d_{n-1}^2 \end{bmatrix} \tag{6}$$

The equations of this system can be solved by the least-squares (LSQ) method with the following formula:

$$x = (A^T A)^{-1} (A^T b) \tag{7}$$

where x is tag coordinate (x, y).

The process of computing RSSI data to produce proximity data between tags is carried out with the process steps illustrated in Fig. 10.

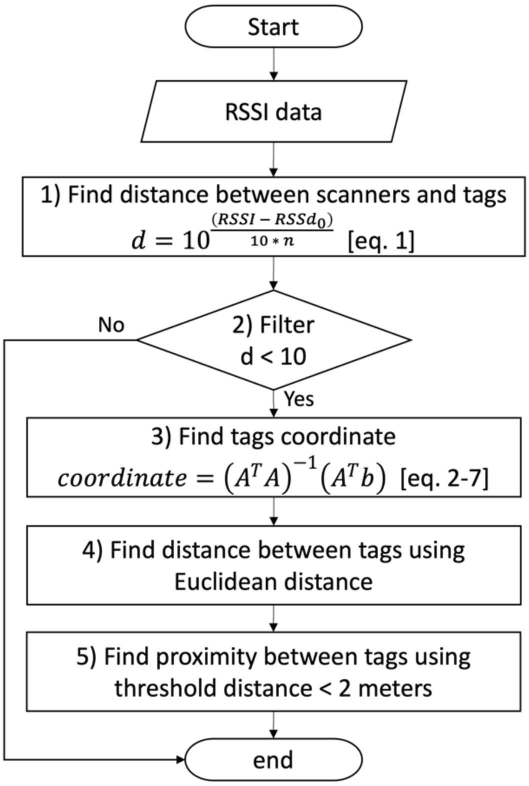


Fig. 10. Process of computing RSSI data to produce proximity

The computation process is carried out per RSSI data saved to a file per specified amount of time; for example, the experiment time is set for 5 minutes, 10 minutes, or 15 minutes. RSSI data is used to calculate the distance between scanners and tags, calculate tags coordinates, then calculate the distance between tags. From the results of the distance between tags, proximity is determined based on the percentage of data with a distance between tags < 2 meters (determined threshold) compared to all data at the specified time interval, in this case, per specified amount of time. This approach is made because, from the results of previous measurements, the statistical value of RSSI mode on the amount of measurement time (5 minutes, 10 minutes, 15 minutes) is quite consistent for measurements at 1 - 10 meters. Therefore, in step 2 of the RSSI computing process, only data with a distance between scanners and tags < 10 meters continue the process.

3 RESULTS AND DISCUSSION

3.1 Results

The simulation uses 10 scanners that are mounted on the ceiling in an area of approximately 11×16 meters, and 4 tags are placed in that area to emit a signal that can be received by the scanner. From the experimental results, the signal emitted by the tags can be read by all scanners at one time if the position of the tag is still reachable by all scanners, and some cannot be read by scanners if the position of the tag is out of the range of the scanners. The tags can be read by 10 scanners at a time if the tags are still within range of the 10 scanners. In order to deal with highly fluctuating signals, a percentage is used to determine proximity. The percentage is obtained from the total distance between tags < distance threshold value, 2 meters, compared to the total distance between tags at a certain time interval (total proximity/total event) and the percentage of proximity duration compared to the event duration, if met > 80%, then the distance between these tags meet the proximity conditions to determine the contact.

From the measurement results of the highly fluctuating transmission signal, especially for distances > 7 meters, it is impossible to determine the exact coordinates of the tags, and this affects the calculation of the distance between tags to determine proximity.

3.2 Discussion

Calibration needs to be done for all devices, both tags, and scanners, to ensure that the device produces a proportional distance range. However, in this study, no device upgrades or improvements were made but focused on measuring existing prototype devices and determining the feasibility of this system device solution from the results of experiments and computations carried out to whether it can fulfill its objectives, namely, a proximity-based COVID-19 contact tracing system devices.

In another study with the same approach where BLE beacons are used to localize people in the house and place scanners at several points in the house, localization calculations using trilateration and fingerprinting algorithms state that high accuracy was obtained [43]. Research by [60] concludes that beacon references (scanners) can be determined which is more optimal by considering the relationships between beacons in monitoring areas. In addition, some studies use Kalman filtering [22], [27], [30], [31], [33], [35] and k-nearest neighbors (k-NN) [38], [39], [61], [62] to overcome transmission signal fluctuations that affect location calculations to obtain more accurate results.

Our research has not considered the improvements made by other studies as mentioned above but rather to test the feasibility and determine computational methods that can be applied to our proposed system. The above studies and many others can be a reference for improving the system for better localization results.

4 CONCLUSION

The proximity-based COVID-19 contact tracing system devices can be developed as an alternative solution to prevent the spread of the virus locally. Proximity can be obtained from the RSSI computing process. If the signal strength emitted by each tag is stable and scanners capture the signal consistently. Further development of this research is first from the Bluetooth technology side to find out whether upgrading the Bluetooth version from 4.0 to 5.0 will obtain better and more accurate measurement results and adding an auto-calibration mechanism to the device, second from the use of technology that can be applied for other purposes such as detecting objects or people by bringing the scanners closer to the object or person being tagged, the third improvement from the computational side to overcome errors in localization calculations.

Acknowledgments

The authors would like to thank the Ministry of Education, Research and Technology, the Republic of Indonesia for Thesis Grant 2022, and LABS247 for partly support.

REFERENCES

[1] World Health Organization, “Contact tracing in the context of COVID-19,” *COVID-19: Surveillance, case investigation and epidemiological protocols*, 2021, https://www.who.int/publications-detail-redirect/contact-tracing-in-the-context-of-covid-19.
[2] World Health Organization, “Coronavirus disease (COVID-19),” https://www.who.int/emergencies/diseases/novel-coronavirus-2019.
[3] World Health Organization, “Digital tools for COVID-19 contact tracing: annex: contact tracing in the context of COVID-19,” *World Health Organization*, 2020, https://apps.who.int/iris/handle/10665/332265.
[4] Government Technology Agency Singapore, “TraceTogether,” *TraceTogether - behind the scenes look at its development process*, 2020, http://www.tracetogether.gov.sg.
[5] D. Koh, “Singapore government launches new app for contact tracing to combat spread of COVID-19,” *MobiHealth*, 2020, https://www.mobihealthnews.com/news/asia/singapore-government-launches-new-app-contact-tracing-combat-spread-covid-19.
[6] Kementrian Komunikasi dan Informatika, “Apa itu PeduliLindungi?,” 2020, https://www.pedulilindungi.id/#tentang.
[7] A. Majeed and S. O. Hwang, “A Comprehensive Analysis of Privacy Protection Techniques Developed for COVID-19 Pandemic,” *IEEE Access*, vol. 9, 2021, https://doi.org/10.1109/ACCESS.2021.3130610.
[8] A. F. Lubis and Basari, “Proximity-Based COVID-19 Contact Tracing System Devices for Locally Problems Solution,” 2020, https://doi.org/10.1109/ISRITI51436.2020.9315498.
[9] P. Sanderson, “Balancing Public Health and Civil Liberties: Privacy Aspects of Contact-Tracing Technologies,” *IEEE Security and Privacy*, vol. 19, no. 4, 2021, https://doi.org/10.1109/MSEC.2021.3077785.
[10] Bluetooth SIG Member, “Intro to Bluetooth Low Energy,” *Bluetooth SIG Inc.*, 2020, https://www.bluetooth.com/bluetooth-resources/intro-to-bluetooth-low-energy.
[11] Bluetooth SIG Member, “Intro to Bluetooth Beacons,” *Bluetooth SIG Inc.*, 2020, https://www.bluetooth.com/bluetooth-resources/intro-to-bluetooth-beacons.
[12] A. A. Kalbandhe and S. C. Patil, “Indoor Positioning System based on Bluetooth Low Energy,” *2016 International Conference on Computing, Analytics and Security Trends (CAST)*, 2016, pp. 451-455, https://doi.org/10.1109/CAST.2016.7915011.

[13] Y. Yun, J. Lee, D. An, S. Kim, and Y. Kim, “Performance Comparison of Indoor Positioning Schemes Exploiting Wi-Fi APs and BLE Beacons,” *2018 5th NAFOSTED Conference on Information and Computer Science (NICS)*, 2018, pp. 124-127, https://doi.org/10.1109/NICS.2018.8606852.

[14] K. N. Alinsavath, L. E. Nugroho, W. Widyawan, and K. Hamamoto, “Integration of indoor localization system using wi-fi fingerprint, bluetooth low energy beacon and pedometer based on android application platform,” *International Journal of Intelligent Engineering and Systems*, vol. 13, no. 4, 2020, https://doi.org/10.22266/ijies2020.0831.15.

[15] Baehaki and B. Soewito, “Optimal scheme fingerprinting localization for indoor positioning system using bluetooth low energy (BLE),” *ICIC Express Letters*, vol. 14, no. 4, 2020, https://doi.org/10.24507/icicel.14.04.379.

[16] K. Phutcharoen, M. Chamchoy, and P. Supanakoon, “Accuracy Study of Indoor Positioning with Bluetooth Low Energy Beacons,” *2020 Joint International Conference on Digital Arts, Media and Technology with ECTI Northern Section Conference on Electrical, Electronics, Computer and Telecommunications Engineering (ECTI DAMT & NCON)*, 2020, pp. 24-27, https://doi.org/10.1109/ECTIDAMTNCON48261.2020.9090691.

[17] M. M. K. Lie and G. P. Kusuma, “A fingerprint-based coarse-to-fine algorithm for indoor positioning system using Bluetooth Low Energy,” *Neural Computing and Applications*, vol. 33, no. 7, 2021, https://doi.org/10.1007/s00521-020-05159-0.

[18] C. K. Ke, M. Y. Wu, Y. W. Chan, and K. C. Lu, “Developing a BLE beacon-based location system using location fingerprint positioning for smart home power management,” *Energies (Basel)*, vol. 11, no. 12, 2018, https://doi.org/10.3390/en11123464.

[19] S. Chai, R. An, and Z. Du, “An Indoor Positioning Algorithm using Bluetooth Low Energy RSSI,” *Proceedings of the 2016 International Conference on Advanced Materials Science and Environmental Engineering*, 2016, pp. 274-276, https://doi.org/10.2991/amsee-16.2016.72.

[20] W. Song, H. M. Lee, S. H. Lee, M. H. Choi, and M. Hong, “Implementation of android application for indoor positioning system with estimote ble beacons,” *Journal of Internet Technology*, vol. 19, no. 3, 2018, https://jit.ndhu.edu.tw/article/view/1704.

[21] R. Ivanov, “Accuracy analysis of BLE beacon-based localization in smart buildings,” *Journal of Ambient Intelligence and Smart Environments*, vol. 13, no. 4, 2021, https://doi.org/10.3233/AIS-210607.

[22] F. Ye, R. Chen, G. Guo, X. Peng, Z. Liu, and L. Huang, “A Low-Cost Single-Anchor Solution for Indoor Positioning Using BLE and Inertial Sensor Data,” *IEEE Access*, vol. 7, 2019, https://doi.org/10.1109/ACCESS.2019.2951281.

[23] L. Ciabattoni, G. Foresi, A. Monteriù, L. Pepa, D. P. Pagnotta, L. Spalazzi, and F. Verdini, “Real time indoor localization integrating a model based pedestrian dead reckoning on smartphone and BLE beacons,” *Journal of Ambient Intelligence and Humanized Computing*, vol. 10, no. 1, 2019, https://doi.org/10.1007/s12652-017-0579-0.

[24] T. M. T. Dinh, N. S. Duong, and Q. T. Nguyen, “Developing a Novel Real-Time Indoor Positioning System Based on BLE Beacons and Smartphone Sensors,” *IEEE Sensors Journal*, vol. 21, no. 20, 2021, https://doi.org/10.1109/JSEN.2021.3106019.

[25] D. Taşkın, “Design of Bluetooth Low Energy Based Indoor Positioning System,” *Balkan Journal of Electrical and Computer Engineering*, vol. 5, no. 2, pp. 60-65, 2017, https://doi.org/10.17694/bajece.334388.

[26] H. Yao, H. Shu, X. Liang, H. Yan, and H. Sun, “Integrity Monitoring for Bluetooth Low Energy Beacons RSSI Based Indoor Positioning,” *IEEE Access*, vol. 8, 2020, https://doi.org/10.1109/ACCESS.2020.3038894.

[27] A. Handojo, T. Octavia, R. Lim, and J. K. Anggita, “Indoor positioning system using BLE beacon to improve knowledge about museum visitors,” *Telkomnika (Telecommunication Computing Electronics and Control)*, vol. 18, no. 2, 2020, https://doi.org/10.12928/telkomnika.v18i2.14886.

[28] R. Bembenik and K. Falcman, “Ble indoor positioning system using RSSI-based trilateration,” *Journal of Wireless Mobile Networks, Ubiquitous Computing, and Dependable Applications*, vol. 11, no. 3, 2020, https://doi.org/10.22667/JOWUA.2020.09.30.050.

[29] N. Pakanon, M. Chamchoy, and P. Supanakoon, “Study on accuracy of trilateration method for indoor positioning with BLE beacons,” *2020 6th International Conference on Engineering, Applied Sciences and Technology (ICEAST)*, 2020, pp. 1-4, https://doi.org/10.1109/ICEAST50382.2020.9165464.

[30] P. Spachos and A. Mackey, “Energy efficiency and accuracy of solar powered BLE beacons,” *Computer Communications*, vol. 119, 2018, https://doi.org/10.1016/j.comcom.2017.12.007.

[31] R. Ramirez, C. Y. Huang, C. A. Liao, P. T. Lin, H. W. Lin, and S. H. Liang, “A practice of BLE RSSI measurement for indoor positioning,” *Sensors*, vol. 21, no. 15, 2021, https://doi.org/10.3390/s21155181.

[32] S. R. Misal, S. R. Prajwal, H. M. Niveditha, H. M. Vinayaka, and S. Veena, “Indoor Positioning System (IPS) Using ESP32, MQTT and Bluetooth,” *2020 Fourth International Conference on Computing Methodologies and Communication (ICCMC)*, 2020, pp. 79-82, https://doi.org/10.1109/ICCMC48092.2020.ICCMC-00015.

[33] N. S. Duong and T. M. D. Thi, “Smartphone indoor positioning based on enhanced BLE beacon multi-lateration,” *Telkomnika (Telecommunication Computing Electronics and Control)*, vol. 19, no. 1, 2021, https://doi.org/10.12928/telkomnika.v19i1.16275.

[34] J. Röbesaat, P. Zhang, M. Abdelaal, and O. Theel, “An improved BLE indoor localization with Kalman-based fusion: An experimental study,” *Sensors (Switzerland)*, vol. 17, no. 5, 2017, https://doi.org/10.3390/s17050951.

[35] P. Supanakoon and S. Promwong, “Evaluation of distance error with bluetooth low energy transmission model for indoor positioning,” *Journal of Mobile Multimedia*, vol. 17, no. 4, 2021, https://doi.org/10.13052/jmm1550-4646.17411.

[36] G. Li, E. Geng, Z. Ye, Y. Xu, J. Lin, and Y. Pang, “Indoor positioning algorithm based on the improved RSSI distance model,” *Sensors (Switzerland)*, vol. 18, no. 9, 2018, https://doi.org/10.3390/s18092820.

[37] D. Sun, E. Wei, Z. Ma, C. Wu, and S. Xu, “Optimized cnns to indoor localization through ble sensors using improved pso,” *Sensors*, vol. 21, no. 6, 2021, https://doi.org/10.3390/s21061995.

[38] D. D. Nguyen and M. Thuy Le, “Enhanced Indoor Localization Based BLE Using Gaussian Process Regression and Improved Weighted kNN,” *IEEE Access*, vol. 9, pp. 143795-143806, 2021, https://doi.org/10.1109/ACCESS.2021.3122011.

[39] G. M. Mendoza-Silva, M. Matey-Sanz, J. Torres-Sospedra, and J. Huerta, “BLE RSS measurements dataset for research on accurate indoor positioning,” *Data (Basel)*, vol. 4, no. 1, p. 12, 2019, https://doi.org/10.3390/data4010012.

[40] R. P. Ghozali and G. P. Kusuma, “Indoor positioning system using regression-based fingerprint method,” *International Journal of Advanced Computer Science and Applications*, vol. 10, no. 8, 2019, https://doi.org/10.14569/IJACSA.2019.0100829.

[41] I. Alexander and G. P. Kusuma, “Predicting indoor position using bluetooth low energy and machine learning,” *International Journal of Scientific and Technology Research*, vol. 8, no. 9, 2019, https://www.ijstr.org/final-print/sep2019/Predicting-Indoor-Position-Using-Bluetooth-Low-Energy-And-Machine-Learning.pdf.

[42] S. Yang, C. Sun, and Y. Kim, “Indoor 3d localization scheme based on BLE signal fingerprinting and 1D convolutional neural network,” *Electronics (Switzerland)*, vol. 10, no. 15, 2021, https://doi.org/10.3390/electronics10151758.

[43] L. Bai, F. Ciravegna, R. Bond, and M. Mulvenna, “A Low Cost Indoor Positioning System Using Bluetooth Low Energy,” *IEEE Access*, vol. 8, 2020, https://doi.org/10.1109/ACCESS.2020.3012342.

[44] T. M. T. Dinh, N. S. Duong, and K. Sandrasegaran, “Smartphone-Based Indoor Positioning Using BLE iBeacon and Reliable Lightweight Fingerprint Map,” *IEEE Sensors Journal*, vol. 20, no. 17, 2020, https://doi.org/10.1109/JSEN.2020.2989411.

[45] A. Riady and G. P. Kusuma, “Indoor positioning system using hybrid method of fingerprinting and pedestrian dead reckoning,” *Journal of King Saud University - Computer and Information Sciences*, 2021, https://doi.org/10.1016/j.jksuci.2021.09.005.

[46] Espressif, “ESP32-DevKitC V4 Getting Started Guide,” *docs.espressif.com*, 2020, https://docs.espressif.com/projects/esp-idf/en/latest/esp32/hw-reference/esp32/get-started-devkitc.html.

[47] S. Bhunia and M. Tehranipoor, “Chapter 3 - System on Chip (SoC) Design and Test,” *Hardware Security*, 2019, https://doi.org/10.1016/B978-0-12-812477-2.00008-3.

[48] Espressif Systems, “ESP32 Series Datasheet,” *Espressif Systems*, 2021, https://www.espressif.com/sites/default/files/documentation/esp32_datasheet_en.pdf.

[49] R. B. Salikhov, V. K. Abdrakhmanov, and I. N. Safargalin, “Internet of things (IoT) security alarms on ESP32-CAM,” in *Journal of Physics: Conference Series*, 2021, vol. 2096, no. 1, https://doi.org/10.1088/1742-6596/2096/1/012109.

[50] V. Thirupathi and K. Sagar, “Implementation of home automation system using mqtt protocol and esp32,” *International Journal of Engineering and Advanced Technology*, vol. 8, no. 2C2, 2018, https://www.ijeat.org/wp-content/uploads/papers/v8i2c2/B10241282C218.pdf.

[51] V. Pravalika and C. Rajendra Prasad, “Internet of things based home monitoring and device control using Esp32,” *International Journal of Recent Technology and Engineering*, vol. 8, no. 1 Special Issue 4, 2019, https://www.ijrte.org/wp-content/uploads/papers/v8i1s4/A10110681S419.pdf.

[52] A. Maier, A. Sharp, and Y. Vagapov, “Comparative analysis and practical implementation of the ESP32 microcontroller module for the internet of things,” *2017 Internet Technologies and Applications (ITA)*, 2017, pp. 143-148, https://doi.org/10.1109/ITECHA.2017.8101926.

[53] Nordic Semiconductor, “nRF51822,” *Nordic Semiconductor*, 2022, https://infocenter.nordicsemi.com/topic/struct_nrf51/struct/nrf51822.html.

[54] MQTT.org, “MQTT: The Standard for IoT Messaging,” *Mqtt.Org*, 2021, https://mqtt.org/.

[55] J. B. Andersen, T. S. Rappaport, and S. Yoshida, “Propagation Measurements and Models for Wireless Communications Channels,” *IEEE Communications Magazine*, vol. 33, no. 1, 1995, https://doi.org/10.1109/35.339880.

[56] P. Pivato, L. Palopoli, and D. Petri, “Accuracy of RSS-based centroid localization algorithms in an indoor environment,” in *IEEE Transactions on Instrumentation and Measurement*, vol. 60, no. 10, 2011, https://doi.org/10.1109/TIM.2011.2134890.

[57] V. Gao, “Proximity and RSSI,” *Bluetooth SIG*, 2015, https://www.bluetooth.com/blog/proximity-and-rssi/.

[58] Silicon Labs Admin, “BLE master/slave, GATT client/server, and data RX/TX basics,” *Silicon Labs*, 2021, https://community.silabs.com/s/article/ble-master-slave-gatt-client-server-and-data-rx-tx-basics?language=en_US.

[59] Silicon Labs, “Developing Beacons with Bluetooth® Low Energy BLE Technology,” *Silicon Labs*, https://www.silabs.com/whitepapers/developing-beacons-with-bluetooth-low-energy-technology.

[60] W. Liu, W. Guo, and X. Zhu, “Map-aided indoor positioning algorithm with complex deployed ble beacons,” *ISPRS International Journal of Geo-Information*, vol. 10, no. 8, 2021, https://doi.org/10.3390/ijgi10080526.

[61] R. K. Yadav, B. Bhattarai, H. S. Gang, and J. Y. Pyun, “Trusted K nearest Bayesian estimation for indoor positioning system,” *IEEE Access*, vol. 7, 2019, https://doi.org/10.1109/ACCESS.2019.2910314.

[62] B. Pinto, R. Barreto, E. Souto, and H. Oliveira, “Robust RSSI-based Indoor Positioning System using K-Means Clustering and Bayesian Estimation,” *IEEE Sensors Journal*, 2021, https://doi.org/10.1109/JSEN.2021.3113837.

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