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A Proof of Concept Using BLE to Optimize Patients Turnaround Time (PTAT) in Health Care

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Abstract:- In 2022, Malaysia's Ministry of Health (MOH) acknowledged that government hospitals continue to face challenges in delivering high-quality patient care. A significant issue is the absence of a Real-Time Patient Location Monitoring and Tracking Solution, which prevents doctors from efficiently tracking patients within medical facilities. This lack of real-time tracking contributes to a decline in service quality, creating an urgent need for optimization in patient monitoring and tracking solutions. Implementing an effective tracking system can significantly enhance patient care quality, improve resource utilization management, and boost staff productivity, ultimately saving costs, time, and resources for hospitals. One critical area for improvement is the Patient Turnaround Time (PTAT), which refers to the duration a patient spends being processed at a hospital before being discharged. PTAT is currently prolonged in many hospitals due to the complex processes involved and patients becoming untraceable while waiting for their turn. To address these challenges, we have developed an Internet of Things (IoT) solution utilizing Bluetooth Low Energy (BLE) technology to optimize PTAT. This solution enables hospital staff to track patient movements and localize them in real-time. By using wearable devices, the system measures the distance from patients to various Access Points (AP) spread throughout the hospital based on the dBm value. This paper presents comprehensive experimentation for the Proof of Concept (POC) and pilot testing of this BLE-based solution. The results demonstrate the accuracy of using the Received Signal Strength Indicator (RSSI) to optimize patient turnaround times in hospitals. By implementing this BLE solution, hospitals can reduce the time patients spend waiting for treatment, thereby improving overall patient satisfaction and hospital efficiency. The ability to monitor patient locations in real-time will ensure that patients receive timely care, reducing the likelihood of them wandering off and becoming untraceable. This technology represents a significant step forward in modernizing patient care and streamlining hospital operations in Malaysia.

Keywords:- *BLE; Healthcare; IoT; Optimization; Patients Turnaround Time (PTAT); Signal Scan.*

I. INTRODUCTION

Hospital overcrowding, delays in receiving timely care, and missed doctor's appointments are pervasive issues in healthcare systems worldwide . These problems are compounded by the extended wait times patients face before being seen by a doctor [1], during which they may wander around the hospital grounds. This wandering makes it challenging for hospital staff to locate patients when their turn comes.Additional complications arise when a doctor finishes with one patient and calls for another from a different department. In such scenarios, patients may move aimlessly from one area to another or respond to calls from other doctors, making it nearly impossible for staff to find them. This lack of coordination leads to inefficiencies and further delays in patient care, exacerbating the problem of prolonged wait times and contributing to the overall decline in healthcare service quality. To address these challenges, the development of a Real-Time Patient Location Monitoring and Tracking Solution is crucial. Such a solution would ensure that patients are easily locatable within the hospital, significantly reducing the time they spend waiting for treatment and improving the overall efficiency of hospital operations.

The Malaysian healthcare system continues to grapple with systemic issues, including a shortage of medical professionals due to the contract system, inadequate infrastructure, unsustainable healthcare financing, and a high prevalence of chronic diseases [2] refer to Figures 1 and 2. Patient Turnaround Time (PTAT) refers to the duration from the moment a patient begins processing at a hospital until they are discharged to return home. This study focuses on the latency in delivering services to patients in Malaysian public hospitals.

Prolonged waiting times for treatment and the inability to monitor and track patients within hospital premises remain significant problems. These issues are intertwined and affect the service quality of public hospitals, specifically in terms of latency and tracking. n 2022, Malaysia's Ministry of Health (MOH) acknowledged that government hospitals continue to face challenges in delivering high-quality patient care. A significant issue is the absence of a Real-Time Patient

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Location Monitoring and Tracking Solution, which prevents doctors from efficiently tracking patients within medical facilities. This lack of real-time tracking contributes to a decline in service quality, creating an urgent need for optimization in patient monitoring and tracking solutions.Implementing an effective tracking system can significantly enhance patient care quality, improve resource utilization management, and boost staff productivity, ultimately saving costs, time, and resources for hospitals. One critical area for improvement is the Patient Turnaround Time (PTAT), which refers to the duration a patient spends being processed at a hospital before being discharged. PTAT is currently prolonged in many hospitals due to the complex processes involved and patients becoming untraceable while waiting for their turn.

To address these challenges, we have developed an Internet of Things (IoT) solution utilizing Bluetooth Low Energy (BLE) technology to optimize PTAT. This solution enables hospital staff to track patient movements and localize them in real-time. By using wearable devices, the system measures the distance from patients to various Access Points (AP) spread throughout the hospital based on the dBm value. This paper presents comprehensive experimentation for the Proof of Concept (POC) and pilot testing of this BLE-based solution. The results demonstrate the accuracy of using the Received Signal Strength Indicator (RSSI) to optimize patient turnaround times in hospitals. By implementing this BLE solution, hospitals can reduce the time patients spend waiting for treatment, thereby improving overall patient satisfaction and hospital efficiency. The ability to monitor patient locations in real-time will ensure that patients receive timely care, reducing the likelihood of them wandering off and becoming untraceable. This technology represents a significant step forward in modernizing patient care and streamlining hospital operations in Malaysia.

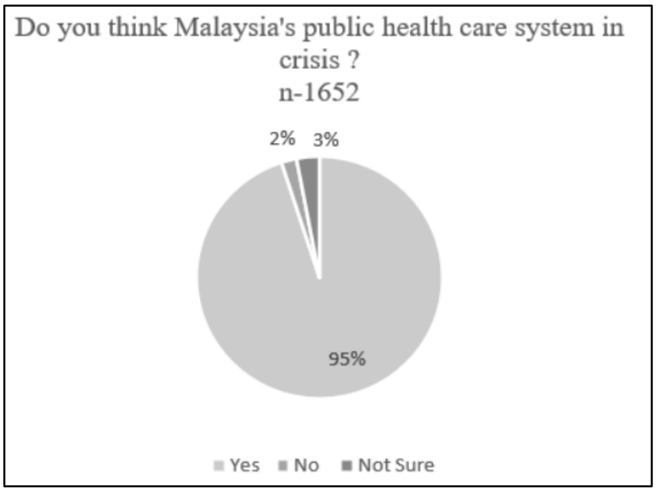

Fig 1 Code Blue Survey: Dissatisfaction among Health Care Professionals and Workers in Malaysia's Government Health Service in 2023

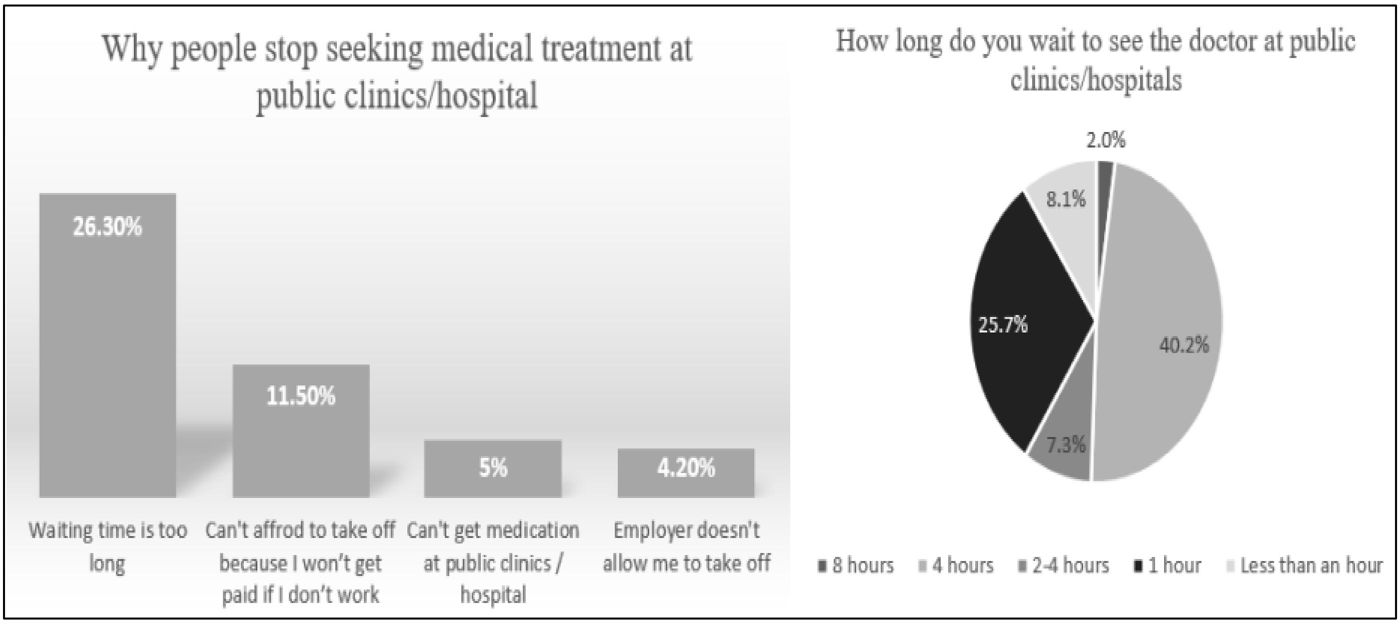

Fig 2 Malay Mail Online's Survey Reveals why People Stop going to Public Hospitals for Medical Care

Currently, PTAT in public hospitals worldwide is highly time-consuming due to numerous processes and the difficulty of locating patients who wander while waiting for their turn. This situation affects more than just individual patients; it significantly reduces productivity and extends the patient turnaround time (PTAT). Figure 3 provides an illustration of how PTAT is calculated. To enhance patient care, it is essential to optimize hospital operations by improving resource management and increasing hospital productivity[3].Hospital staff often cannot locate patients within the facility, leading to missed appointments even though the patients are present. According to Malaysia's Ministry of Health, these issues contribute to widespread dissatisfaction among the public, medical professionals, and patients [4] . Thus, improving the quality of care and managing resources more effectively at medical facilities is crucial. However, combining localization and monitoring into a single comprehensive solution for PTAT has proven to be a challenging task, with few studies or solutions successfully addressing both aspects.

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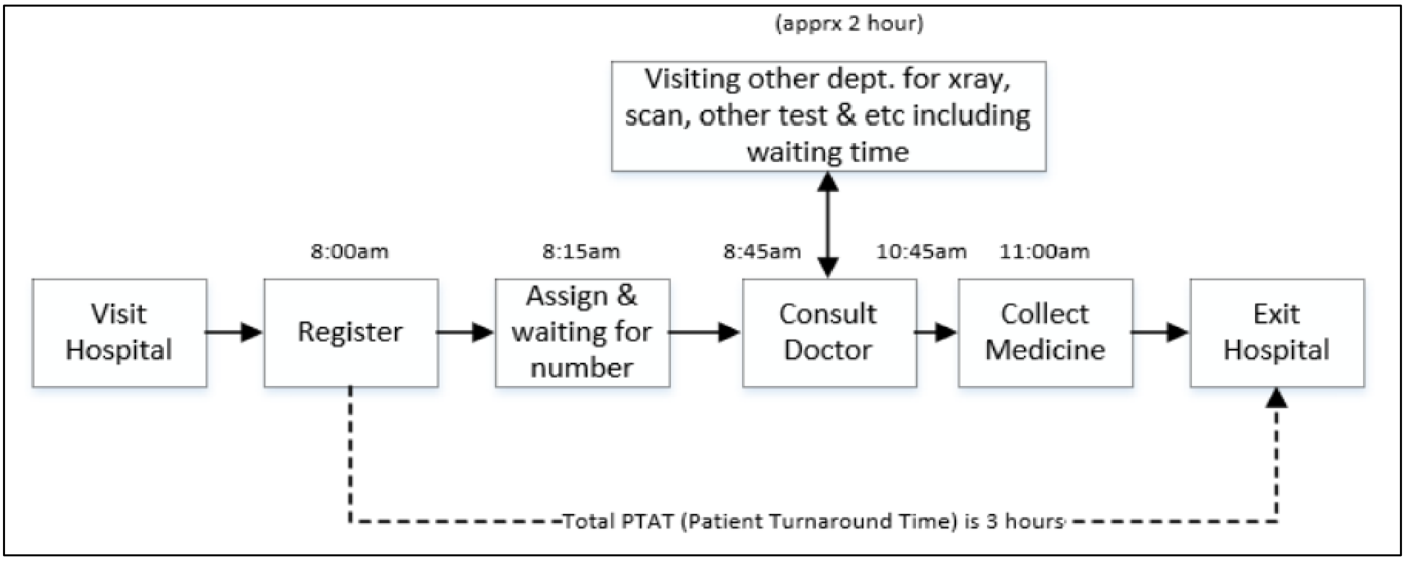

Fig 3 How Patience Turnaround Time is Calculated

It is crucial to propose a solution to expedite developments as the world transitions into an era of "Smart Healthcare" [5]. An effective and comprehensive Real-Time Patient Location Tracking solution [6] will primarily rely on Bluetooth Low Energy (BLE) and the Internet of Things (IoT) . BLE facilitates monitoring, while IoT handles data collection and processing. In this system, each patient will receive a BLE-tagged wristband upon admission. Each tag will contain essential patient information, such as the device ID, AP name, and other specifics. As patients move throughout the hospital, access points (AP) mounted on walls and ceilings will collect location data from the tags and transmit it to a cloud database for storage and analysis. Refer to Figure 4 for an architectural diagram of the system.

Low-calibrated transmission power wearable devices are utilized to estimate the locations of patients, with the Received Signal Strength Indicator (RSSI) value obtained as shown in the flowchart above. Patients receive RSSI signals via their wearable devices, and a system server uses an access points and locations mapping table to match the estimated nearest beacons transmitted from the patient's device to the relevant subareas' locations.

We tested the proof of concept using the technique illustrated in Figure 5 below, employing 3 access points and 8 wearable devices.

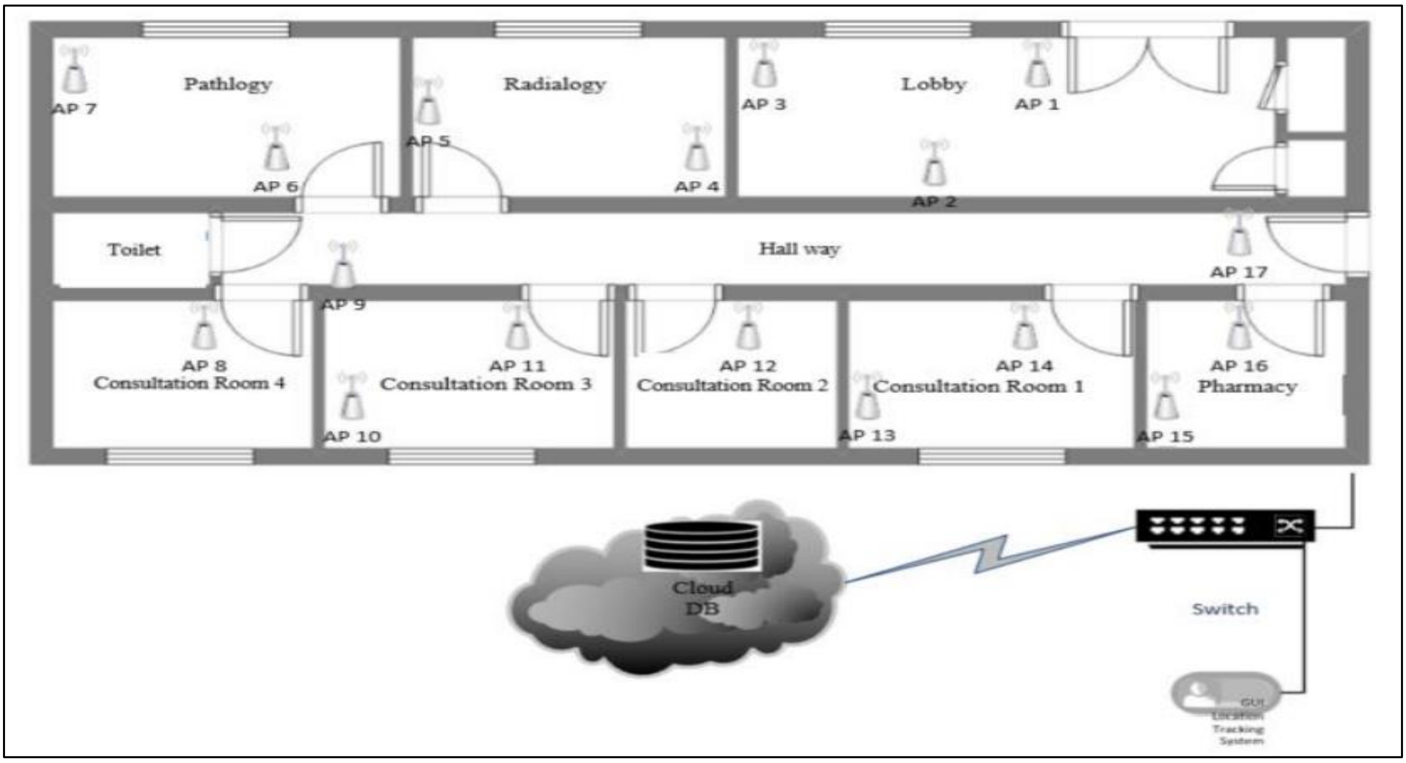

Fig 4 Real Time Patient Location Tracking Solution Architecture

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In simple terms, RSSI (Received Signal Strength Indicator) measures the antenna's ability to receive power, with larger RSSI numbers (small negative values) indicating stronger signals[7] . As the signal travels further, it weakens, causing the RSSI value to decrease over distance [8-9]. Every BLE chipset has a maximum RSSI sensitivity (maximum negative value), which varies by model. Once this sensitivity threshold is reached, the chipset can no longer detect incoming signals.RSSI is a crucial metric for determining the effectiveness of a device in picking up signals from networks or access points. It helps determine if the signal strength is sufficient for establishing a reliable wireless connection. It's important to note that RSSI is distinct from the transmit power of a router or access point [10] because it is derived from the Wi-Fi card of the client device. Each received packet can have its received signal intensity (energy) evaluated.

The received signal strength indication (RSSI) is determined by quantifying the observed signal energy. MAC, NWK, and APL layers have access to both the RSSI and the packet reception time (timestamp) for various forms of analysis[11] .Although the units of measurement for dBm and RSSI are different [12], they both indicate signal strength. RSSI is a relative index, whereas dBm represents power levels in milliwatts.RSSI can typically be measured on a scale of 0 to 255, with each chipset manufacturer choosing their own "RSSI Max" number according to the IEEE 802.11 standard, which encompasses specifications for building Wi-Fi equipment. For instance, Cisco employs a scale of 0-100, while Atheros uses a scale of 0-60. The manufacturer has full control over these scales, but generally, a higher RSSI score indicates a better signal strength.

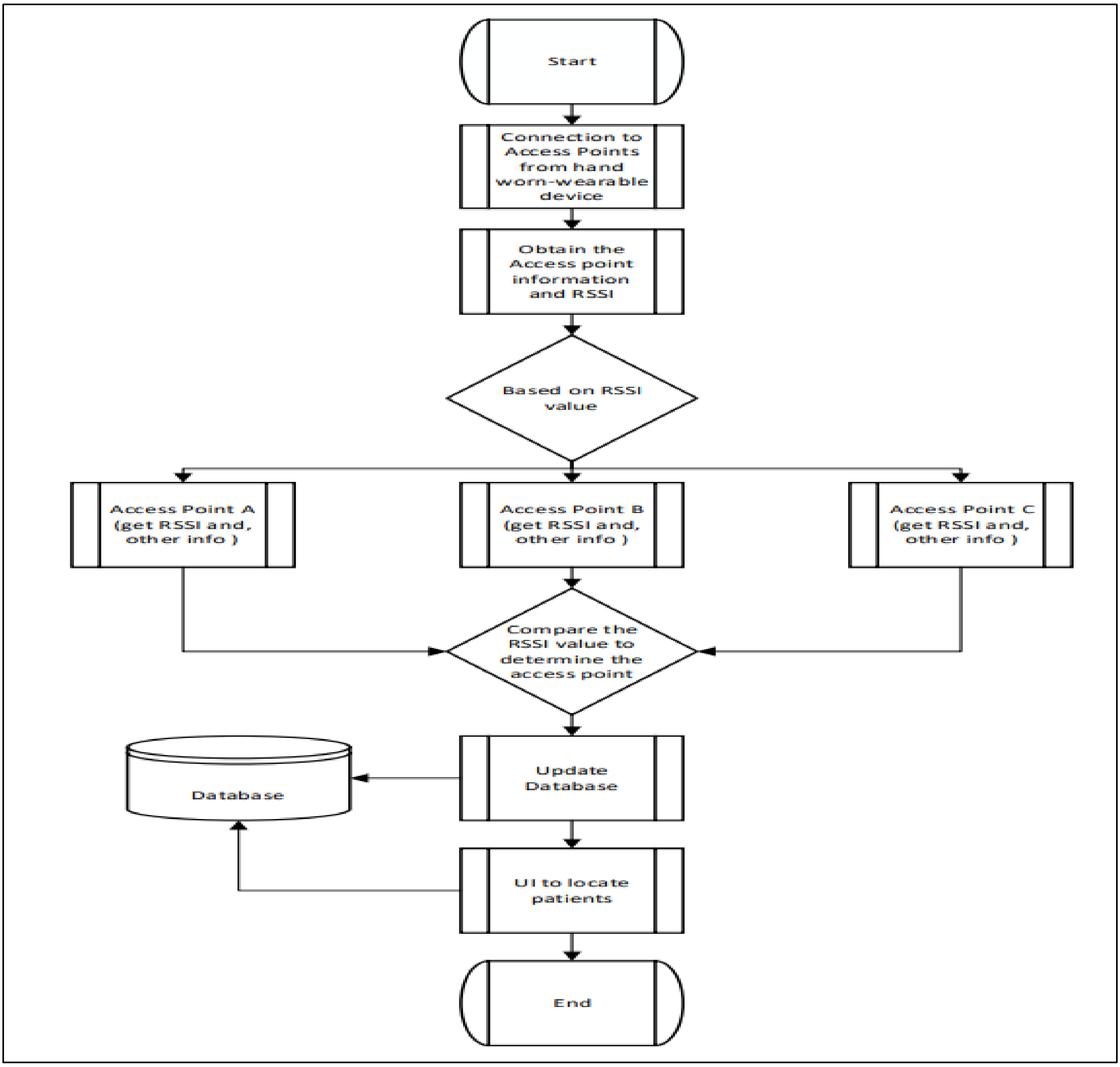

Fig 5 Flow Chart of Positioning Algorithm

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The initial phase of the experiment involves determining the average reference RSSI value, RSSI, at a distance of 1m for Bluetooth applications[13] . Additionally, it is essential to observe the maximum RSSI value at a distance of 5m for the specified transmitted power. Table 1 presents the results of this preliminary experiment conducted with the experimental BLE device utilizing the nRF52832 chipset, as illustrated in Figure 6. The experiment utilized the nRF52832, a versatile Bluetooth 5.2 system on a chip (SoC) with a maximum RSSI sensitivity of -96 dBm [14-15].

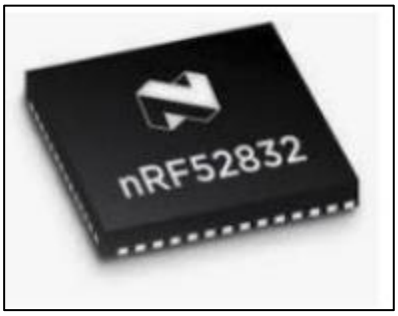

Fig 6 nRF52832 Chipset

Table 1 illustrates that both devices exhibit typical RSSI values of -35 dBm at a distance of 0 meters. Comparable trends were observed at the other two distances, with a slight variance observed at 1 meter. However, a marginal difference of only -1 dBm does not suggest inaccuracies in the data obtained.Both devices demonstrated average maximum RSSI values ranging from -88 dBm to -94 dBm at a distance of 5 meters, which will be utilized. A higher value indicates that the user's distance exceeds 5 meters.

Table 1 Results for RSSI Measurement for four Different Distances using Two Devices under Line-of-Sight Condition

Device Number, n	**Condition**	**Distance,** m in meters	**Average RSSI,** $RSSI_{avg}$
1	No obstacle – Line of sight	0	-34.01
2			-36.43
1		1	-50.01
2			-52.13
1		3	-67.12
2			-68.15
1		5	-88.45
2			-89.14

Nonetheless, the average of the RSSI is acquired using the below formula to determine the RSSI reference point.

$$for\ m = 1, RSSI_r = \frac{(RSSI_{avg1} + RSSI_{avg2})}{2}$$

Per the Figure 7 below, there are three primary steps for this experimentation in this study. They are: (1) Setting Up the environment for obtaining RSSI and testing, (2) Proof of Concept (POC) for confirming the suggested technique,and (3) Pilot Test for putting the recommended approach to the test in a real-world setting. It should be noted that this strategy and testing procedures are repeatable with other BLE devices as well.

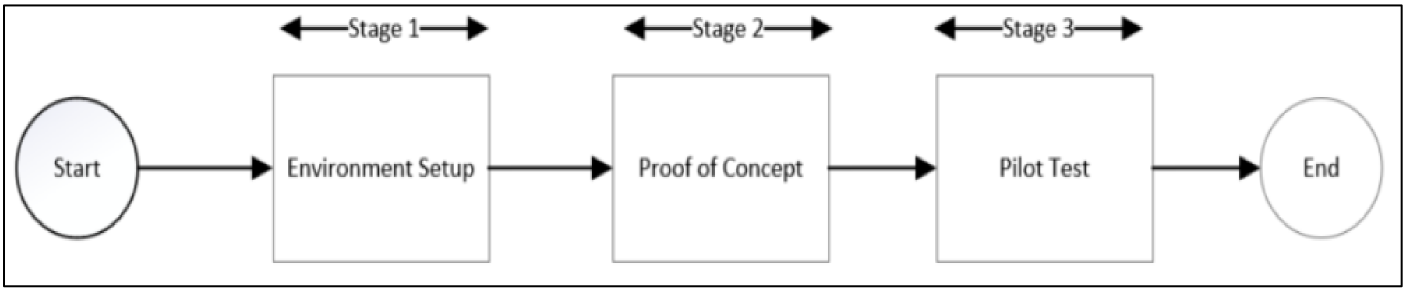

Fig 7 Stages of the Experiment

II. METHODS

➢ *Experimentation Environment Setup*

Applications involving point-of-interest (PoI) information fall under the proximity solutions category. For instance, in hospitals, these applications can help users locate specific departments. Additionally, proximity solutions include features for finding lost or misplaced items, such as Bluetooth tags. In these implementations, Bluetooth tags frequently broadcast BLE frames. Access points (APs) scan these frames to gather Bluetooth tag data, which is then transmitted to the location server (AC) via the access controller (AC). Identifying points or PoIs that are near the computed location is essential in PoI proximity applications.

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The experimental setup for simulating the deployment of a Real-Time Patient Location Tracking Solution involves several step. Utilizing the existing WiFi network. Establishing a floor plan within a private clinic. Configuring environmental parameters such as AP Name, model name, channel, bands, etc. Placing access points (APs) strategically on the floor plan. Adjusting the locations and parameters of the APs as necessary. Reviewing the planned setup to anticipate outcomes. Capturing and uploading data to the database. Setting up the database to store the captured data. Figure 6 illustrates the placement of APs on the clinic's floor plan for experimentation purposes. This setup aims to acquire RSSI values to determine distances and identify the nearest access point, thus providing patient location status in real-time.

In this study, readings were taken from five nRF52832 System on Chips (SoCs) powered by a 5V lithium-ion battery . The purpose of the Proof of Concept was to verify if the technique functions as expected under optimal conditions and to potentially provide distance estimates as an additional benefit. Two nRF52832 SoCs were utilized in the Proof of Concept to measure RSSI readings at various distances for Line of Sight (LOS) conditions under perfect circumstances. By employing Access Points (APs) to capture data packets from these client devices, the use of two BLE modules ensures the detection of any deviations. The chipsets transmit advertising packets to the Access Point every 50ms (this interval may vary depending on the scenario), while the AP scans every 5 seconds. Subsequently, the collected data was inputted into a database. The captured data includes the following components: Medium Access Control Address (Mac address), Access Point, Device Name, RSSI value, Date, and Time.

With a maximum transmission power (Tx) of -4 dBm, it is more than capable of serving as the transmitter for testing the low-calibrated Tx technique for near location tracking. In this study, Tx is set at -8 dBm, which is deemed optimal because the Received Signal Strength Indicator (RSSI) reaches -96 dBm at a distance of 5 meters. In the Proof of Concept section, a sample size of measurements ranging from -100 to -200 dBm was employed to ensure the acceptability and reliability of the data. It is important to note that the experiment was conducted in a controlled setting devoid of additional network connectivity or barriers[17].Both the sender and receiver were elevated to 0.5m simultaneously to simulate true wearables on the wrist and provide a direct angle. Figure 8 illustrates the Proof of Concept experiment setup, while Table 2 presents a sample of the data gathered from the scan.

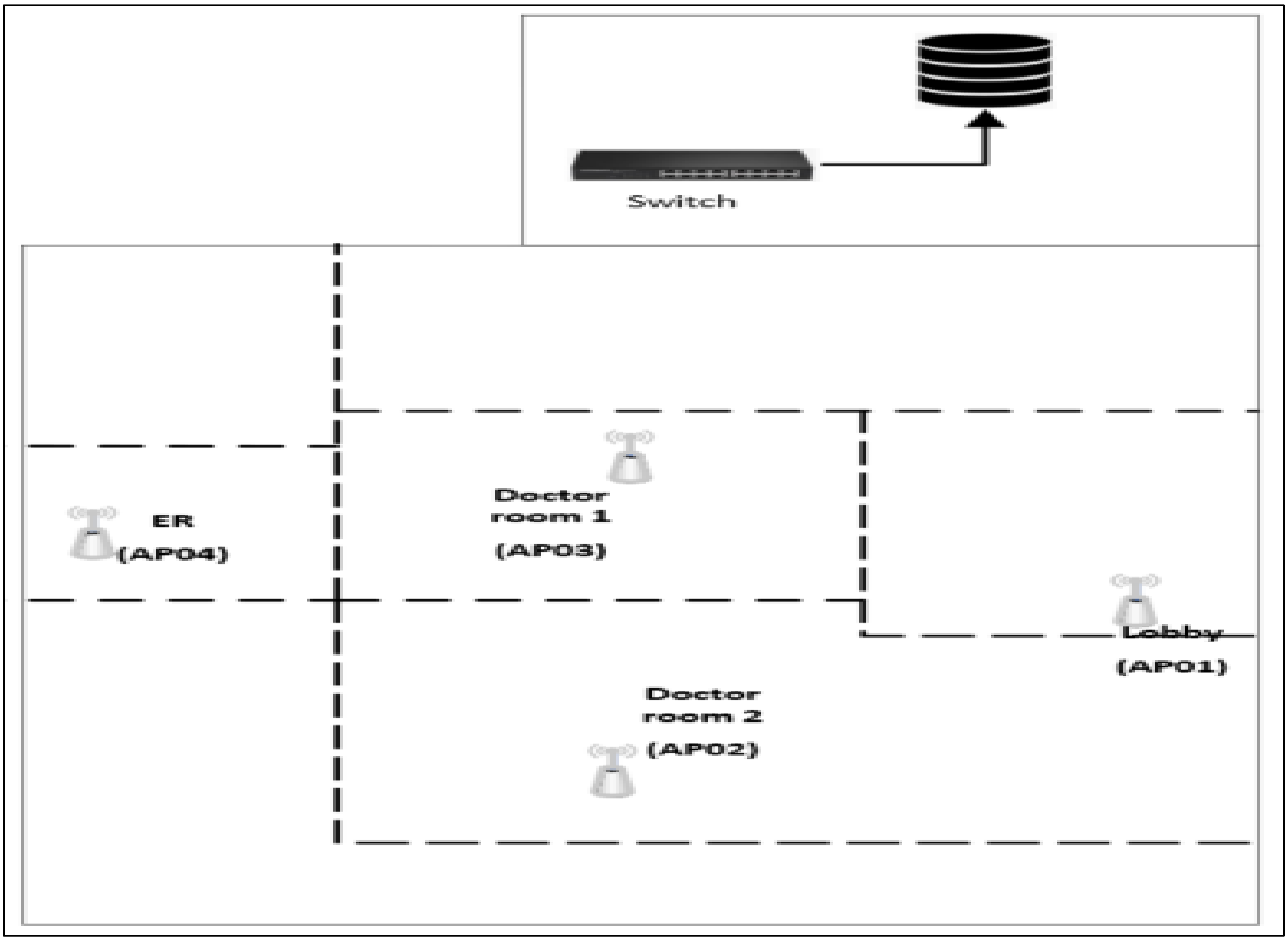

Fig 8 Stage 1 Experimentation Set Up

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The collected data was organized and structured in a database, mirroring the information gathered during the proof of concept phase. Devices were elevated to a height of 7m to simulate real-world wearing conditions of wearables. The inclusion of four devices was deliberate, aiming to evaluate the approach's ability to accommodate multiple users and assess the number of successful scans for different angles of arrival (AOA).

Table 2 Sample of Captured Data

Access Point	AP Address	Device Name	Device Address	RSSI Value	Date	Time
AP01	00:1B:44:11:3A:B7	BLETag1	01:1C:44:11:3B:B8	-50 dBM	25/03/2023	11:00:44
AP02	01:1C:44:11:3B:B8	BLETag2	02:1C:44:11:3B:B9	-25 dBM	25/03/2023	11:23:59
AP03	00-14-22-01-23-45	BLETag3	04:1C:44:11:3B:B10	-10 dBM	25/03/2023	11:19:41
AP01	01-23-45-67-89-AB	BLETag4	05:1C:44:11:3B:B11	-15 dBM	26/03/2023	11:25:17
AP04	00-14-22-01-23-BC	BLETag5	01:1C:44:11:3B:B12	-7 dBM	26/03/2023	11:51:20

For the second stage of Proof of Concept (POC) experimentation, multiple devices were utilized, with a maximum of 20 devices in total, consisting of 16 wearable devices and 4 Access Points (APs). The experimentation involved distances ranging from 1m to 5m, with multiple positions set to simulate various real-life scenarios. The objective was to assess the concept under ideal conditions for multiple real-life scenarios. Figure 9 illustrates the setup for the POC in stage 2, where "Person 1" is positioned nearest to a specific Access Point (AP) based on the RSSI value. It's important to note that the RSSI value will vary depending on the distance from the Access Point. The primary goal of the POC was to verify whether the approach is functional before proceeding to the next stage of development.

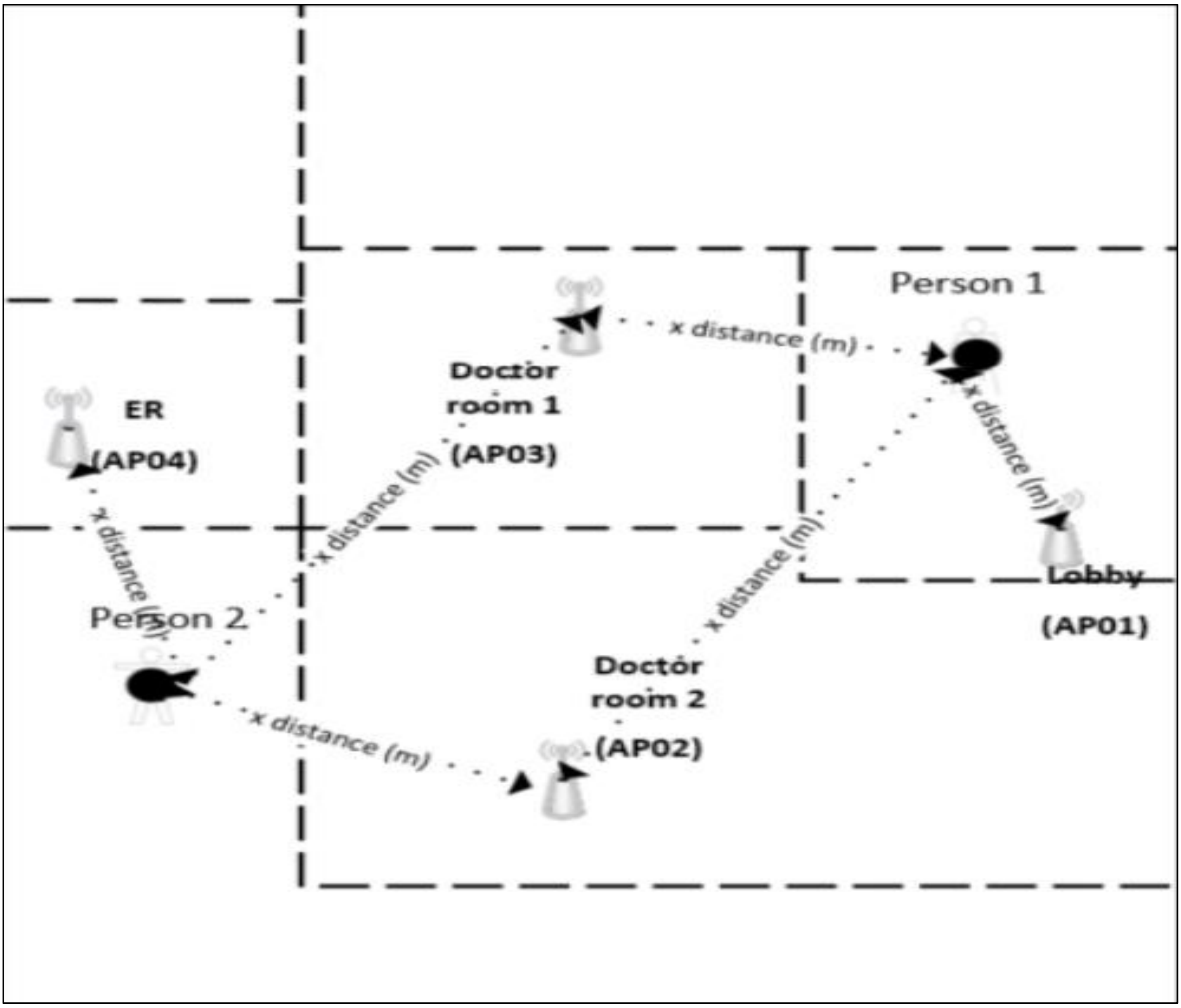

Fig 9 Stage 2 Experimentation Set Up

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Stage 3 represents the Pilot test phase, where experimentation was conducted in an indoor environment involving 5 users. The environment included multiple doors and walls nearby, with users intermittently walking by. This stage is pivotal as it determines the feasibility of implementing the approach in a real-world scenario. During Stage 3, nRF52832 chipsets were integrated into BLE wearable devices and distributed to the 5 users for a duration of 2 hours. Users were instructed to move from one department to another within the main lobby area. Each time a user passed an Access Point, a record with the RSSI value was created. The distances tested ranged from 1 to 5 meters, with each session lasting no less than 30 minutes. Upon completion of the 2-hour period, the wearables were collected, and the data were analyzed by comparing the information obtained from the wearables with the users' records. Furthermore, during registration, patients were provided with BLE wearable tags labeled as "BLETag1," "BLETag2," and so forth, which were mapped to the respective patient's name. A sample summary of the data collected is presented in Table 3.

Table 3 Summary Data of Experimentations Set up for Three Stages

Access Point	AP Address	Device Name	Device Address	RSSI Value	Date	Time
AP01	00:1B:44:11:3A:B7	BLETag1	01:1C:44:11:3B:B8	-45 dBM	27/03/2023	09:01:41
AP02	01:1C:44:11:3B:B8	BLETag2	02:1C:44:11:3B:B9	-12 dBM	27/03/2023	09:13:19
AP03	00-14-22-01-23-45	BLETag3	04:1C:44:11:3B:B10	-50 dBM	27/03/2023	09:18:34
AP01	01-23-45-67-89-AB	BLETag4	05:1C:44:11:3B:B11	-13 dBM	27/03/2023	10:23:57
AP04	00-14-22-01-23-BC	BLETag5	01:1C:44:11:3B:B12	-9 dBM	27/03/2023	10:05:50
AP04	00-14-22-01-23-BC	BLETag1	01:1C:44:11:3B:B12	-67 dBM	27/03/2023	10:07:30
AP03	00-14-22-01-23-BC	BLETag3	01:1C:44:11:3B:B12	-90 dBM	27/03/2023	10:09:40
AP04	00-14-22-01-23-BC	BLETag5	01:1C:44:11:3B:B12	-65 dBM	27/03/2023	10:30:50

III. ANALYSIS AND RESULTS

➢ *Stage 1 Testing - Set Up*

Initially, as depicted in Table 4 below, the value was intentionally set to ensure the device operates at its maximum RSSI sensitivity of -89dBm at a distance of 5 meters following thorough testing and evaluation. This deliberate adjustment aimed to account for potential errors arising from physical barriers, as well as varied Angles of Arrival (AOAs) and elevations that may be encountered during subsequent stages of real-world implementations. Although the RSSIavg number may not precisely match the chipset's maximum level at 5 meters, this approach was adopted to enhance the device's robustness. The results of the stage 1 experiment are presented in Table 4.

Table 4 Findings from Stage 1 of the Experiment

Device Number, *n*	Distance, m in meters	Observations	Max RSSI Value, $RSSI_{max}$	Min RSSI Value, $RSSI_{min}$	Average RSSI Value, $RSSI_{avg}$
1	0	100	-39	-33	-35
2			-37	-32	-35
1	1		-78	-66	-71
2			-75	-70	-72
1	2		-90	-77	-83
2			-86	-78	-82

Table 3 illustrates minimal variance between the data collected from the two devices. This suggests a successful experiment, indicating that the Tx (transmission power) has been effectively calibrated for the nRF52832 in this study, with only a 1dBm difference in the average value. However, it's worth noting that over a distance of 2 meters, the disparity between the RSSImax and RSSImin can reach a maximum of 4dBm. While this difference is relatively small, it may still be perceptible. Referring to Table 2, the Tx is set at -8 dBm, and at a distance of 2 meters, the RSSI approaches -83.

➢ *Stage 2 – Proof of Concept*

Applications providing users with location-based information, such as those found in hospitals' point-of-interest (PoI) departments, are categorized under proximity solutions. This category also encompasses features for locating lost or misplaced items, such as Bluetooth tags. In these implementations, Bluetooth tags frequently transmit BLE broadcast frames. Access points (APs) analyze these frames for Bluetooth tag information, which is then relayed to the location server via the access controller (AC). It is essential to identify the points or PoIs that are in close proximity to the computed location in PoI proximity applications.

Positioning systems encompass location-based services that utilize Bluetooth technology to accurately determine the location of a device. These systems are particularly valuable for indoor positioning and real-time people monitoring, aiding individuals in navigating challenging interior environments. In indoor positioning scenarios, applications must estimate the precise location of encountered beacons to calculate the monitored device's position accurately. This necessitates knowledge of the beacon's known location,

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including its x- and y-coordinates for horizontal positioning, as well as its elevation relative to a reference height for three-dimensional positioning.Determining the position of the host device requires information on the direction of the received signal, the expected distance to the beacon, and the beacon's location. Without this data, the application cannot accurately determine the position of the host device.

Bluetooth beacon technology is enabled by the Bluetooth Low Energy (BLE) specification. A beacon emits a unique ID, which is received by an application on a BLE device. This application then queries a database to retrieve information about the transmitting beacon's position and provides it to the user.The methods used to determine the distance between the BLE device and the beacon are depicted in Fig. 10. Triangulation-based location estimation leverages the Bluetooth direction finding feature to measure the angles from two or more reference points to a specific point. This information is then used to calculate the point's location based on the known distances between the reference points

These angles can be either Angle of Arrival (AoA) or Angle of Departure (AoD), which are utilized in the triangulation technique. While distance measurements are implemented directly, triangulation utilizes angle measurements. With this technique, the location of any point in 2-D can be calculated by considering the three angles between the point and three reference points. In 2-D space, estimating the position of every point requires a minimum of two angles. Denoting the distances between Bluetooth beacons A–B, B–C, and A–C as dAB, dBC, and dAC respectively, and the known angle measurements between the BLE device and Bluetooth beacons A, B, and C as x, y, and z respectively, the triangulation approach allows for the computation of angles. Utilizing these known data, the position of the BLE device can be determined.Triangulation is a challenging approach that requires knowledge of the positions and spatial orientations of the Bluetooth beacons. However, it offers a more precise determination of the BLE device's position compared to trilateration, thanks to its AoA and AoD capabilities.

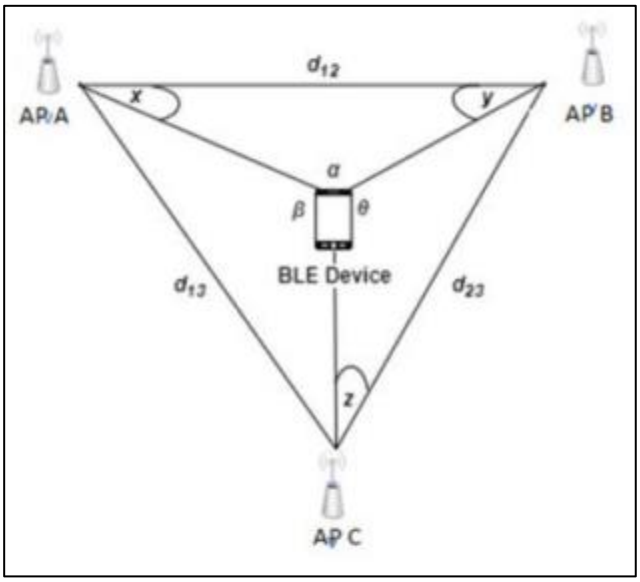

Fig 10 Triangulation-Based Location Estimation

In this stage, I collected 10 RSSI samples at each grid point and computed RSSI values at various distances. Figure 11 and subsequent figures illustrate changes in RSSI at distances of 1 and 2 meters from the access point. These data were gathered using the latest Bluetooth specification module, Bluetooth Low Energy (BLE), designed specifically for Internet of Things devices. As previously mentioned, due to the congested interior environment in which these studies were conducted, occasional fluctuations in RSSI of 10 to 12 dBm were observed. Similar patterns were also observed when two BLE devices were positioned 3 or 4 meters apart, as depicted in Figures 12 and 13. This trend persisted even when the separation distance was increased to 10 meters.

	1	2	3	4	5	6	7	8	9	10
RSSI (1m)	-68	-65	-66	-67	-70	-72	-67	-72	-71	-67
RSSI (2m)	-73	-75	-76	-72	-75	-76	-77	-80	-79	-76

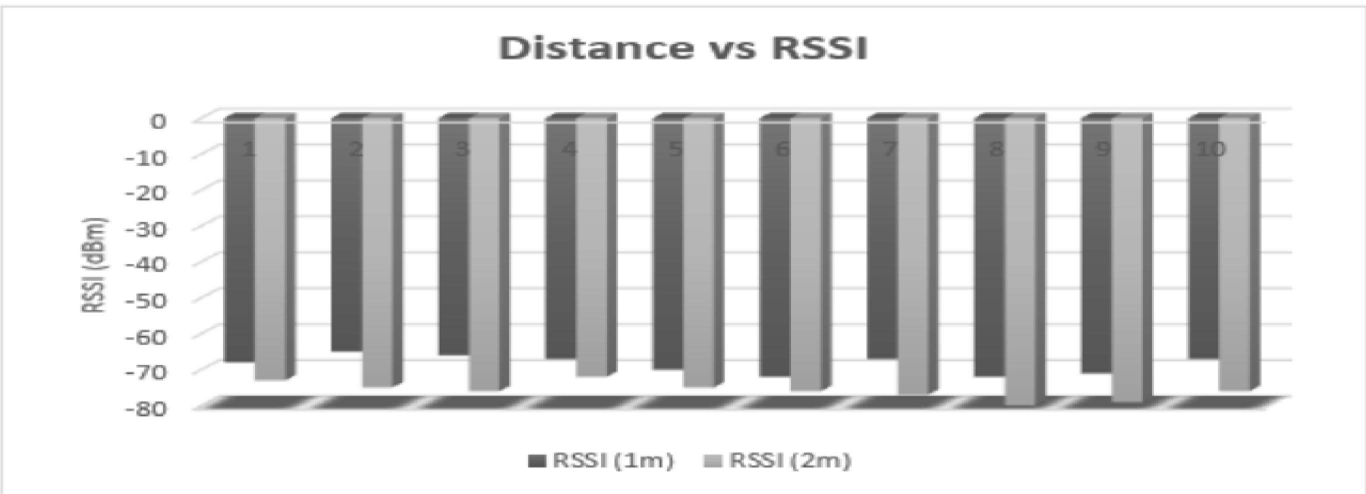

Fig 11 Received Signal Strength Indicator (RSSI) Samples at 1 and 2 m

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	1	2	3	4	5	6	7	8	9	10
RSSI (3m)	-70	-82	-80	-87	-75	-80	-85	-76	-80	-76
RSSI (4m)	-79	-84	-86	-89	-82	-82	-90	-83	-89	-90

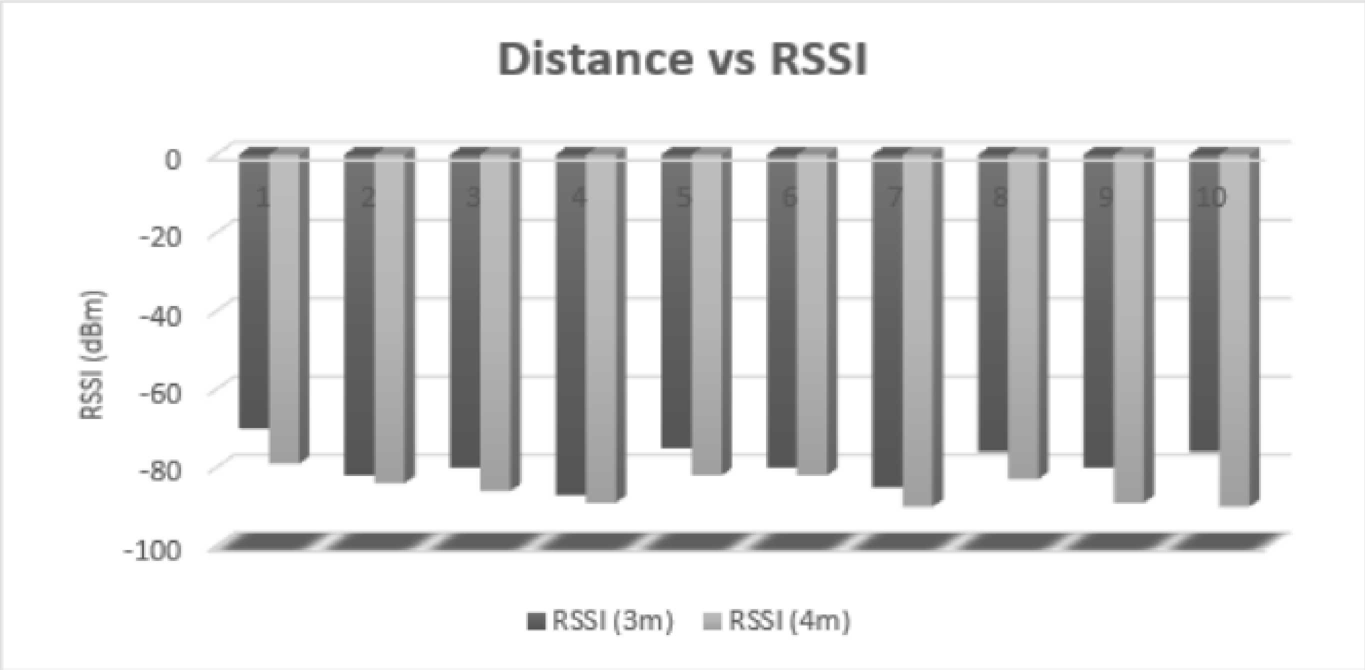

Fig 12 Received Signal Strength Indicator (RSSI) Samples at 3 and 4 m

	1	2	3	4	5	6	7	8	9	10
RSSI (5m)	-93	-96	-90	-89	-91	-94	-89	-88	-92	-93
RSSI (6m)	-95	-98	-97	-94	-99	-104	-97	-97	-101	-96

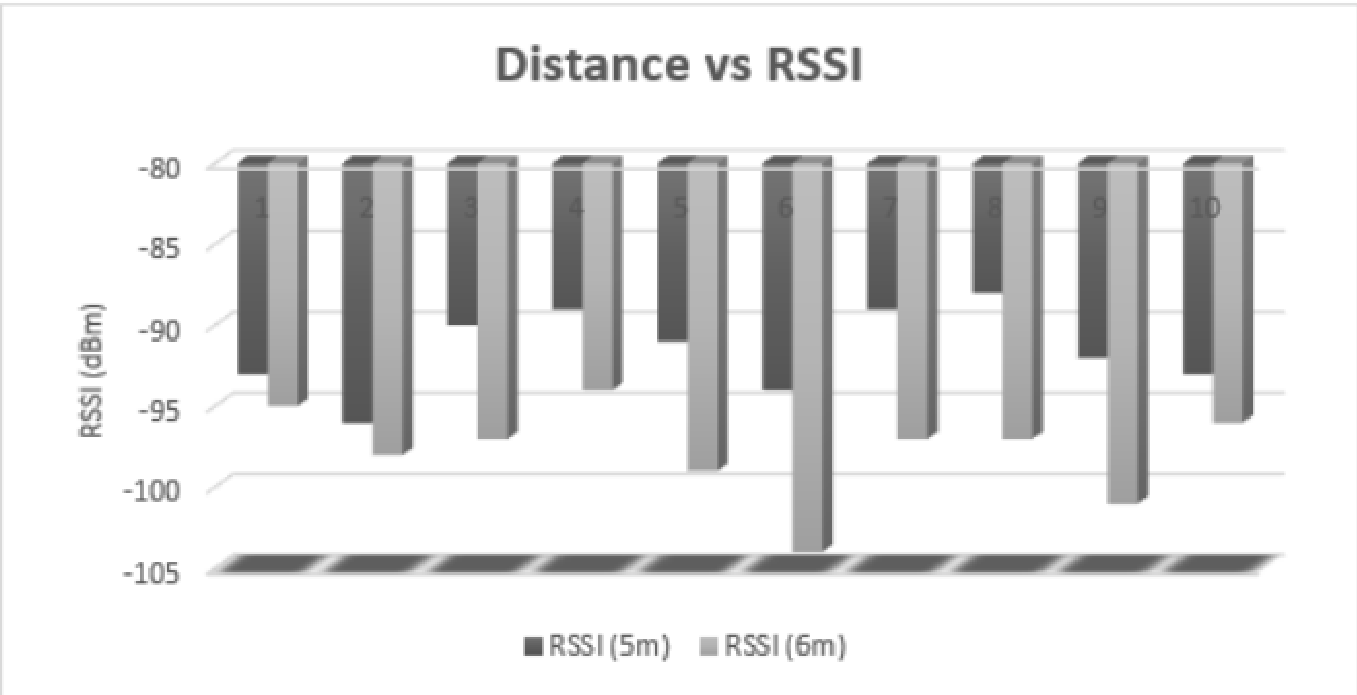

Fig 13 Received Signal Strength Indicator (RSSI) Samples at 5 and 6 m

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In the conducted experiments, we observed an average RSSI variation of 10 dBm. Additionally, we noted that the RSSI inquiry mode exhibited latency issues. To measure RSSI, we developed a Python application that utilized the inquiry mode. Alternatively, another approach involves establishing a connection between two Bluetooth devices. However, for location-based applications, connectivity-based methods are not practical. Instead, tracking-based applications often rely on the inquiry-based strategy.

➢ *Stage 3 – Pilot Test*

Two widely recognized path-loss models, namely the free-space radio propagation model and the logarithmic distance path-loss model, are commonly employed for indoor navigation and localization purposes. Recent research suggests that the logarithmic path-loss radio propagation model is favored by most indoor positioning systems for estimating distance from RSSI values.The logarithmic path-loss model, represented by Formula 5, is formulated as follows: [Formula 5]

$$RSSI = -10n\log(d) + A \quad (1)$$

In the logarithmic path-loss model (Formula 5), 'n' represents the path-loss constant, and 'd' signifies the estimated distance determined by RSSI. According to literature studies, the value of 'n' in indoor environments typically falls within the range of 1 to 4.The variable 'A' denotes the RSSI when two BLE devices are separated by 1 meter. However, the maximum value of 'n' is contingent upon changes in RSSI induced by disturbances or physical obstacles within interior environments. The accurate estimation of distance and modeling of radio propagation constants using RSSI poses a challenging issue. Precise RSSI values and radio propagation constants are essential for achieving accurate distance estimation. Therefore, selecting optimal values for 'n' and 'A' necessitates the modeling of radio propagation constants. These values are summarized in Figure 14.The first row of Figure 14 depicts the real distance, i.e., the distance between the Access Point (AP) and a variable BLE module, represented by decimal numbers ranging from 1 to 6. The second row displays average RSSI values obtained from real-time experimental research, along with the number of scan averages.

Estimation Distance	1	2	3	4	5	6
RSSI (avg)	-68	-75	-79	-85	-91	-97
Number of Scan	5	7	7	8	9	9

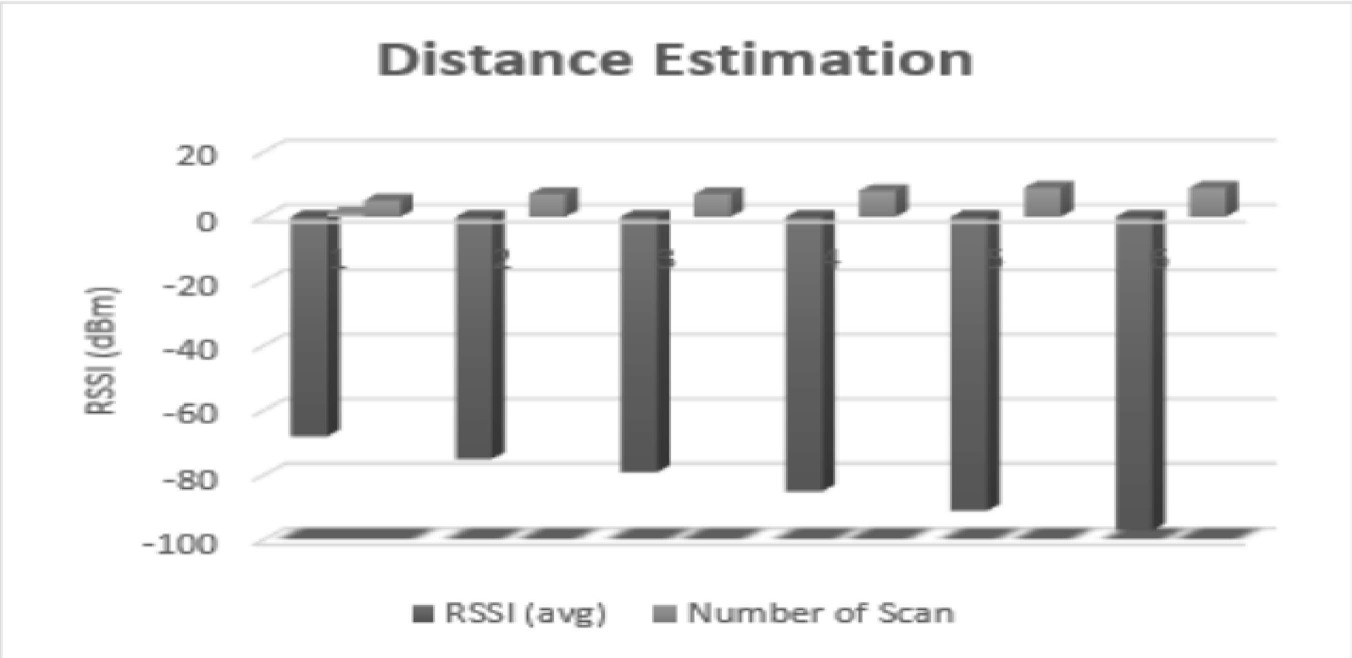

Fig 14 Stage 3 Experimentation Results

In the case of Bluetooth, signal strength is influenced by both the distance traveled and the broadcasting power setting. Bluetooth signals are transmitted through broadcasting, with Received Signal Strength Indicator (RSSI) values typically ranging from -6 to -100. To calculate Bluetooth proximity between two connected or unpaired devices and a beacon, a different metric called Measured Power, also known as the 1 Meter RSSI, can be utilized. Measured Power is a read-only constant that is factory calibrated and indicates the expected RSSI at a distance of 1 meter from the beacon.However, it's important to note that RSSI tends to fluctuate due to external factors affecting radio waves, such as diffraction, interference, or absorption. As the device moves farther away from the beacon, RSSI becomes more erratic. By using Measured Power and RSSI, it's possible to calculate the

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distance between the device and the wearable tag, as per Formula 2: [Formula 2]

Distance = 10^((Measured Power -RSSI)/(10*N)) (2)

Where N is a constant that depends on environmental factors. It ranges from 2 to 4 (low to high strength).

For example, if Measured Power is -69 and obtained RSSI value is -80, with N=2 (low strength), then calculated

Distance = 10^((-69 - (-80))/(10*2)) = 3 meters.

This stage of experiment proves that the approach can be utilized in real-life application and has the potential for bigger number of users for the public hospital in Malaysia.

- *How Real-Time Patient Localization and Patient Movement Monitoring Improve the PTAT*

One prevalent issue in healthcare institutions is hospital congestion, exacerbating patients' wait times as they endure lengthier processing periods before seeing a doctor. This delay often prompts patients to roam the hospital premises, posing challenges for staff in locating them. Moreover, complications may arise if a patient is summoned by a doctor from a different department, leaving their whereabouts uncertain as they move between departments or respond to other doctor calls. To address these challenges, Real-time Patient Localization and Patient Movement Monitoring systems are employed. The shaded area in Figure 15 signifies where significant improvements in patient turnaround time can be achieved through the implementation of the Real Time Patient Location Tracking System. Upon arrival at the hospital, each patient is provided with a BLE-tagged wristband containing essential patient data, including an ID number and access point information. Readers, referred to as Access Points (AP), installed on the walls and ceilings throughout the hospital and its vicinity, collect data on the tags' locations as patients navigate the facility. This data is then transmitted to a cloud database for further processing and analysis.

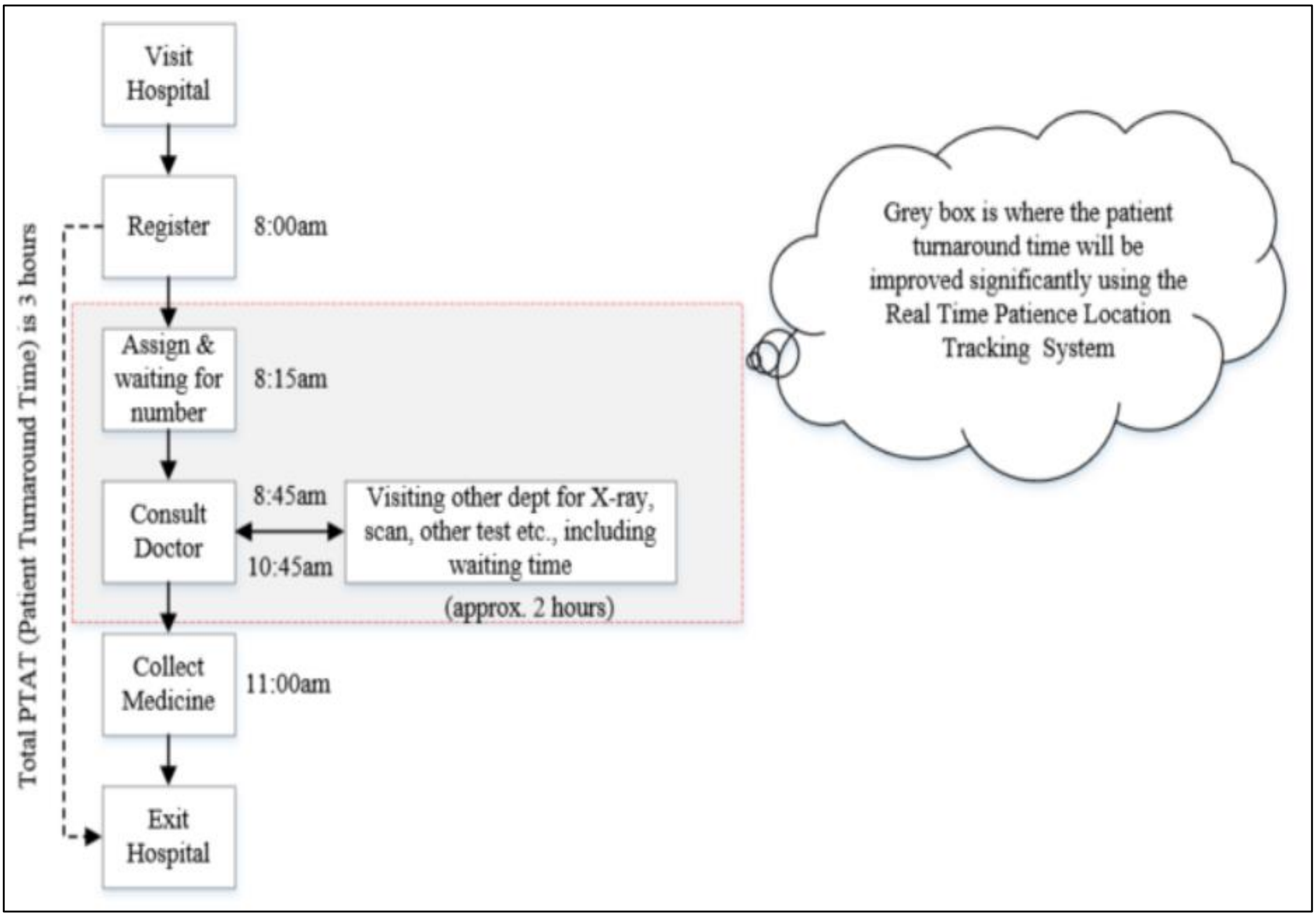

Fig 15 Stage 3 Experimentation Results

The implementation of the Real-Time Patient Location Tracking and Movement Solution also leads to a reduction in the turnaround time for patients receiving treatment. This is achieved through the staff's or doctors' improved ability to promptly locate patients and communicate with them as needed. Table 4 provides a comparison of the benefits associated with implementing the Real-Time Patient Location Tracking and Movement Solution.

Table 4 Comparison of Benefits before and after Implementation of Real Time Patient Location Tracking and Movement Solution

Description	Before	After
Registration	✓	✓
Patient missed Doctor's consultation due whereabout in hospital	✓	×
Trackable after registration	×	✓
Locate the Patient where about within hospital	×	✓
Faster Doctor consultation	×	✓
Improve the Quality of Service (QoS)	×	✓
Optimize the throughput of the departments	×	✓
Saving Time	×	✓
Cost saving	×	✓
Patients are happy	×	✓

IV. DISCUSSION

According to the study's findings, utilizing low-calibrated Tx for real-time patient location tracking has proven to be highly accurate and successful in reducing patient turnaround times (PTAT). However, certain limitations and areas for improvement have been identified. For instance, mass testing has not yet been conducted, but it could be a potential future direction for academic research before practical implementation. Additionally, there are constraints such as a limited number of devices and distance testing, suggesting the need for further experimentation, ideally at 1-meter intervals, to ensure consistent accuracy. The study highlights that as the number of devices increases, the success rate of scans decreases due to the finite time between scans by the receiver. Adjusting this variable could enhance precision or accommodate more users, striking a balance between the number of users and the scanning interval to achieve optimal RSSI accuracy.

Moreover, while a high percentage of successful scans may create the impression of high accuracy, it's essential to consider the broader context. Real-time patient location tracking has demonstrated its potential to significantly reduce patient wait times in Malaysian public hospitals. Therefore, there's a pressing need to identify hospital requirements, leverage advanced technologies like BLE and the Internet of Things, and integrate them effectively to optimize benefits for patient turnaround times in healthcare settings.

V. CONCLUSION

We employed low-calibrated Tx in our proposed method to effectively carry out Real-Time Patient Location Tracking, aiming to enhance Patient Turnaround Time (PTAT). In this approach, RSSI is used as a supplementary tool for estimating distance, based on the number of successful signal scans. Experimentation indicated that our proposed solution yielded positive and accurate results. Real-time patient location tracking demonstrated a high degree of accuracy in reducing patient wait times. Consequently, implementing a low-calibrated Tx approach for Real-Time Patient Location Tracking to enhance PTAT is a viable tool or method that implementors can utilize to better manage patient flow. To conserve energy and increase tracking sensitivity, future implementations of the Real-Time Patient Location Tracking system could incorporate BLE chipsets with even lower power consumption.

DECLARATIONS

- *Author Contributions*

Conceptualization, G.R.M.A.; methodology, G.R.M.A. and S.M.; software, G.R.M.A.; validation, S.M., ; formal analysis, G.R.M.A and S.M; investigation, G.R.M.A.; writing—original draft preparation, G.R.M.A.; writing—review and editing, S.M.; supervision, S.M.; project administration, K.S.M.A.; All authors have read and agreed to the published version of the manuscript.

- *Data Availability Statement*

The corresponding author can provide the data described in this study upon request.

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- *Conflicts of Interest*

The author declares that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies have been completely observed by the authors.

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