Development of Prototypical Indoor Real-time Location System for Medical Equipment Management Based on BLE Devices

Teerawit Assawasillapakul[1], Nutdanai Singkhleewon[1]*, Kanlaya Thanasin[1], Amonrat Khambun[1]

[1]Faculty of Sciences and Technology, Bansomdejchaopraya Rajabhat University, Bangkok
[1]1061 Itsaraphap Rd, Hiranruchi, Thonburi District, Bangkok
Mar6666@hotmail.com

Abstract

Generally, healthcare is considered the fastest growing business and largest service industry in the world. However, hospitals are typically large buildings with various equipment spread over multiple floors. The positioning and tracking of assets in indoor environments have great potential to assist staff in locating needed equipment without wasting time searching for it. Therefore, this research proposes the development of the prototypical indoor real-time location system (RTLS) based on Bluetooth Low-Energy technology devices for any equipment tracking in test scenario. The ESP32 microcontroller is used as the transceiver node in each room to receive the MAC address of the HM-10 beacon attached to the equipment within range and transmit data to a web server. A data filter is applied to reduce noise from Received Signal Strength value for distance between node and beacon calculation. The efficiency test results show that the average distance error between beacon and node is around 3 m, and the maximum duration of location updating from node to node in the scenario is no more than 15 seconds. It can be concluded that if equipment with beacon is in the tracking area of the node, then the presence status of the equipment in each room can be correctly transmitted to the web server.

Keywords : Real-time Location Tracking System, Medical Equipment Location Tracking System, Bluetooth Low Energy Devices, Indoor Tracking System.

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1. INTRODUCTION

Mobile technology has the potential to solve a wide range of everyday issues. NFC, GPS, Wi-Fi, and beacons are examples of developing mobile technologies that are becoming increasingly essential in daily life. Among these technologies, beacons that use Bluetooth Low Energy (BLE) to broadcast small pieces of information have become the most recent version of wireless technology. BLE consumes low energy and can transmit various types of data, including ambient and micro-location data for asset tracking. This technology can be used for Real-Time Location System (RTLS), which collects data from tags and map locations using algorithms based on Received Signal Strength Indicator (RSSI) measurements. The recent advancements in healthcare have motivated researchers to improve accessibility, especially in preventing equipment absence during medical demands.

Azeez, A. et al. [1] developed a real-time location system (RTLS) that combines hardware, sensors, and software to collect, analyze, and provide location data for moving objects in real-time. The RTLS uses both fixed nodes and mobile computer units to gather information for navigation, monitoring, and tracking applications. Ewing, A. et al. [2] demonstrated the application of RTLS in healthcare, where various entities such as patients, employees, medical equipment, samples, and prescriptions can be tracked in real-time. According to their research published in the 2017 Systems and Information Engineering Design Symposium [2], RTLS provides accurate timestamps and location information, calculated using distance, range, duration, or direction. The utilization of RTLS helps to estimate average wait time and optimize patient flow, as reported by Ramirez [3] in his research, "A Business case for using Real Time Locating Systems for Medical Equipment". This leads to an improvement in the efficiency of medical services.

According to a study by Wang, B.T. et al. [4], the cost of RTLS infrastructure can be reduced if it can be reused in healthcare settings, such as when Wi-Fi infrastructure has already been installed. However, adding additional Access Points (APs) to increase detection range and precision will increase the total cost of ownership. On the other hand, BLE-based RTLS is found to be more cost-effective than active RFID in terms of ease of use and widespread adoption, as noted in the study by Osman, M. et al. [5], BLE offers superior characteristics for various environments, including lower cost and high accuracy for nearby proximity tracking applications. Additionally, the widespread use of Bluetooth Low Energy (BLE) as a communication protocol in mobile and wearable devices for Personal Area Network (PAN) systems further supports the scalability, simplicity, and low cost of BLE-based RTLS, making it a promising option for RTLS deployment in the healthcare industry.

The goal of this research is to develop a framework for a location-based service using beacons and microcontrollers with BLE, which will be developed on affordable devices to track the real-time location of medical assets on a floor plan map. This will improve many processes in medical treatment and reduce equipment absence issues by providing quick access to assets in case of maintenance, normal use, or emergencies. In addition, the immediate dispatch of assistance to patients and medical professionals in the event of an emergency can be facilitated by knowing the location of assets

2. MATERIALS AND METHODS

2.1 Design the hardware infrastructures.

The location tracking system uses Beacon devices as tags to monitor the location of devices within a building. The system will identify locations using ESP32 Node devices, which will detect beacons and send information to a computer display. The prototypical system has two components: the tracking device hardware and the display information system. In this article, will not discuss the development of this information system.

1. The ESP32 is a microcontroller board optimized for developing IoT applications that require both Wi-Fi and dual-mode Bluetooth. With its dual-core or single-core Tensilica Xtensa LX6 microprocessor, built-in antenna switches, and various RF components, the ESP32 offers high efficiency and versatility for developers. Additionally, its inclusion of the powerful ESP8266 microcontroller makes it a popular choice for projects that require low-power and high performance.

Small radio transmitters, known as beacons, that use Bluetooth technology can detect physical locations and trigger actions on nearby smart devices by transmitting contextual data. As shown in Figure 1(B), the HM-10 iBeacon-2032 is a standalone

Bluetooth Smar proximity beacon that uses iBeacon technology and is housed in a CR2032 battery-sized package. The identity and additional bytes can be used to track the beacon, determine its physical location, or initiate location-based activities on the device, such as a push notification or social media check-in

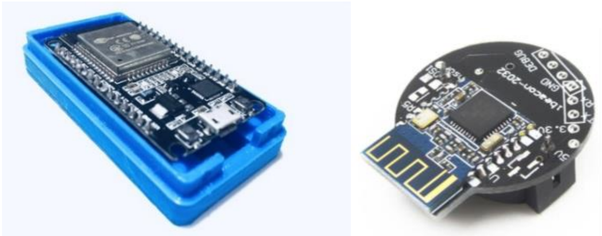

Figure 1. A) Node ESP32 B) Beacon

The design of the location tracking system is depicted in Figure 2. It starts by establishing the positions of each "node" in the database. Then, the nodes will link to the network and pick up Bluetooth signals from nearby "beacons" within a range of 2.5 meters. When a connection is made, the node and beacon exchange information, with the node retrieving the MAC address of the beacon and verifying it against the database's records. This data is then displayed on a computer screen as a list of devices and their current positions. The verification process (shown in Figure 3) starts by logging the status of the device connected to the beacon, then using the obtained beacon data to compare it to the system's records to determine the device's location. The information is constantly updated in real-time, enabling continuous monitoring of the device's location

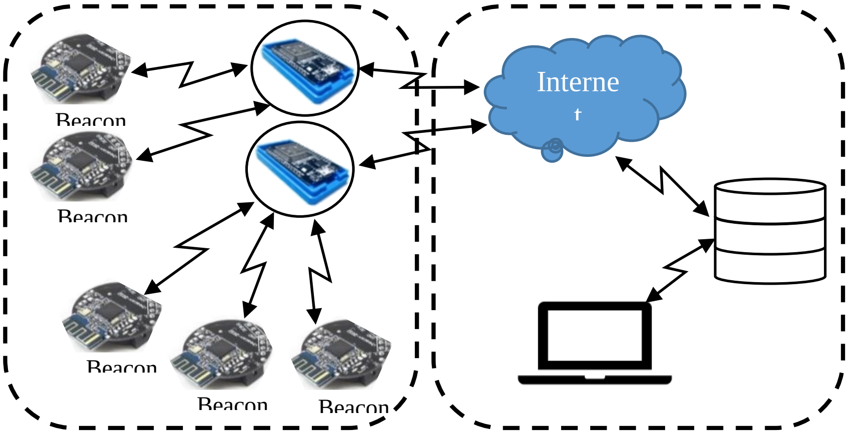

Figure 2. Diagram of prototypical location tracking system

2.2 The software development

From Figure 3, once the configuration in the device account is complete, the beacon device status will be sent to the server via the internet. This allows the device status information to continue to be recorded in the location tracking database. The device detection system will then restart its search for surrounding devices until either the internet connection is lost, or the system is stopped.

While the solution to find the distance between BLE devices is to use a log-distance path loss model, which estimates the distance based on the RSSI value and the signal strength at a reference distance. The formula for this model is:

$$dis\tan c\, e(in\ meters) = 10^{((MeasuredPower-RSSI)/(10*0))} \qquad ..... (1)$$

where: 1) Measured Power is the RSSI value at a reference distance (In the test used value = -69, known as the 1 Meter RSSI). 2) RSSI is the RSSI value being measured. 3) n is the path loss exponent, which is a measure of the loss of signal strength over distance (2-4 dBm).

However, the use of RSSI alone can lead to inaccurate results due to external factors such as interference. The solution to this problem is to use a median filter to filter out the noise and improve the accuracy of the measurement.

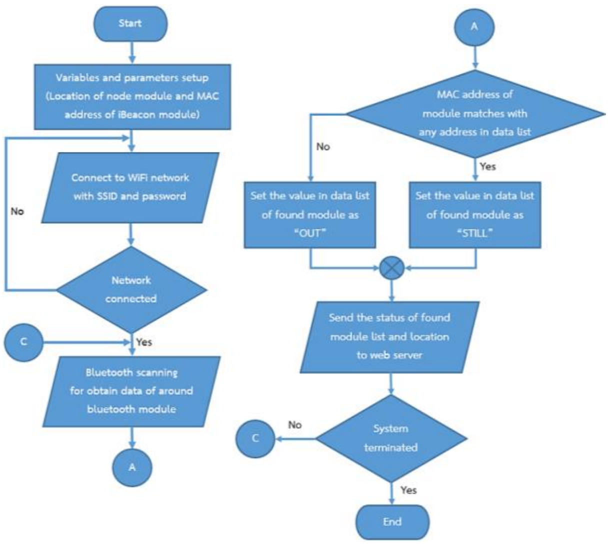

Figure 3. Data communication flow chart

2.3 RESULTS AND DISCUSSION

Initial evaluation of the measured distances between the beacon and node was carried out in 3 sample open space rooms, where a node was installed in each room. The beacon was then relocated to various rooms to determine the distance between the devices as measured by the node. The findings of this study are presented in Figure 4.

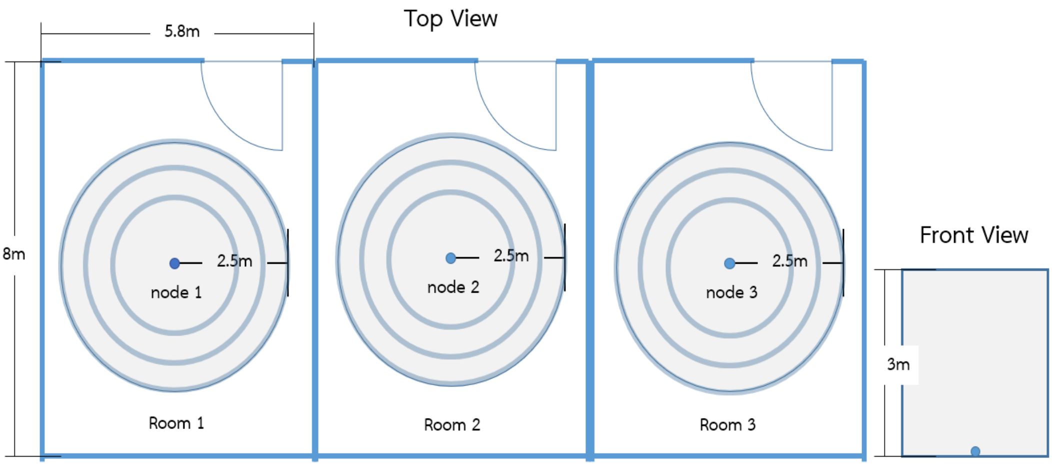

Figure 4. Evaluation of the ability to detect beacon devices in sample locations.

As indicated in Figure 4, the results showed that the node was capable of correctly identifying the beacon device through its device ID and could accurately determine the distance between the node and the beacon when they were in close range proximity 2-5 meters. This level of accuracy was deemed sufficient for determining the location of the device within the designated area.

This research scenario was carried out at Building 9, Floors 8 and 9 of Bansomdejchaopraya Rajabhat University. 16 nodes were installed in various rooms and 10 beacons were placed in a simulated medical device box and distributed to different rooms, then moved between them as shown in Figures 5 and 6.

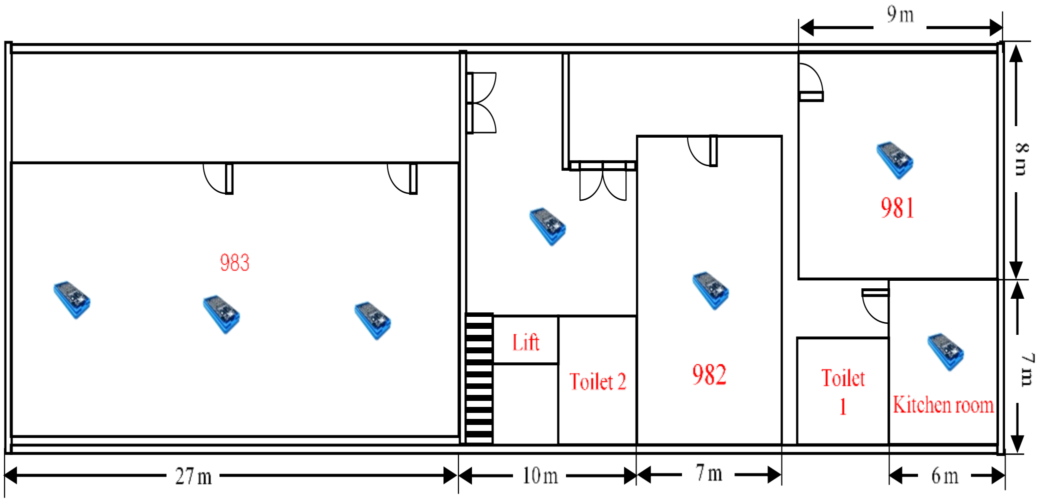

Figure 5. Devices location on 8th floor scheme.

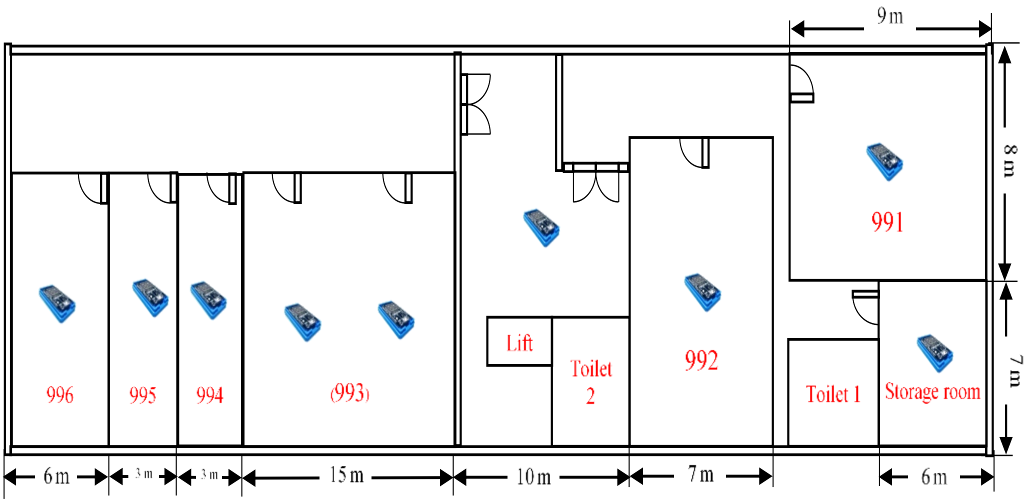

Figure 6. Devices location on 9th floor scheme.

The distance values obtained from using the RSSI method to measure the distance between every beacon and node were not the same as the real distance due to several external factors affecting the strength of the signal and leading to inaccurate distance calculations. These factors include obstacles, interference, and the presence of other wireless signals. Despite this, the location of the beacons can still be determined in the scenario, as shown in Table 1, 2, and Figure 7.

Table 1: Result of the beacons detection on the 8th floor.

Device detection test on 8th floor				
981	982	983	Lobby	Kitchen room
Detected	Detected	Detected	Detected	Detected

Table 2: Result of the beacons detection on the 9th floor.

Device detection test on 9th floor							
991	992	993	994	995	996	Lobby	Storage room
Detected	Detected	Detected	Detected	Detected	Detected	Detected	Detected

DATE	DEVICE NAME	ID CODE	CURRENT AREA	STATUS	ACTION
24 Nov 2021 - 04:24	Electrosurgical units	ESUNIT-ER0000-60-002	981-1	out	History
24 Nov 2021 - 04:23	Syringe Pump	SYRPUM-PED000-60-003	981-1	stay	History
24 Nov 2021 - 04:22	Defibrillators	DEFRIB-LR0000-60-001	981-1	stay	History
24 Nov 2021 - 04:22	HamiltonC1	C10000-CE0000-60-002	981-1	stay	History
24 Nov 2021 - 04:19	Secretion Suction,Mobile	SUCMOB-ICU000-60-001	981-1	stay	History
24 Nov 2021 - 04:08	Infant Incubator	INFINC-PED000-60-002	982-In	out	History
24 Nov 2021 - 03:54	Patient Monitor	PATMON-AN0000-60-001	981-1	stay	History
08 Feb 2022 - 11:28	Electrocardiograph	EKG000-MW1000-60-001	992-Front	stay	History
08 Feb 2022 - 10:36	Bennett	840000-ICU000-60-003	995	out	History
07 Feb 2022 - 16:23	Patient Monitor	PATMON-PED000-60-016	981-1	out	History

Figure 7. Simulated medical equipment location information display.

As the results, the average error in distance between the beacon and node is approximately 2-3 meters, and the maximum duration for updating the location from node to node in the scenario is no more than 15 seconds.

The prototype system was tested in an experiment and demonstrated the ability to function as a real-time location system (RTLS), using a combination of hardware, sensors, and software to collect, analyze, and provide location data for moving objects in real-time. These results are consistent with a study by Azeez, A. et al [1], which found an average error in distance between the beacon and node of approximately 2-3 meters and a maximum duration of 15 seconds for updating location information from node to node.

From the results, it can be applied in healthcare, as demonstrated by Ewing, A. et al. [2], where patients, employees, medical equipment, samples, and prescriptions can be tracked in real-time. This technology provides accurate timestamps and location information, calculated using distance, range, duration, or direction, as reported in the 2017 Systems and Information Engineering Design Symposium. The utilization of RTLS helps to estimate average wait time and optimize patient flow, leading to an improvement in the efficiency of medical services, as noted in research by Ramirez [3].

While the cost of RTLS infrastructure can be reduced if it can be reused in healthcare settings, adding additional Access Points (APs) to increase detection range and precision will increase the total cost of ownership, according to Wang, B. et al. [4]. However, BLE-based RTLS is a promising option for RTLS deployment in the healthcare industry due to its scalability, simplicity, and low cost, as noted in a study by Osman, M. et al. [5]. BLE offers superior characteristics for various environments, including lower cost and high accuracy for nearby proximity tracking applications. The widespread use of Bluetooth Low Energy (BLE) as a communication protocol in mobile and wearable devices for Personal Area Network (PAN) systems further supports the adoption of BLE-based RTLS in the healthcare industry.

3. CONCLUSIONS

The proposed real-time location system (RTLS) based on Bluetooth Low-Energy technology devices and the ESP32 microcontroller is a cost-effective solution for indoor equipment tracking in healthcare.

The average distance error between the beacon and the node was found to be around 3 m, and the maximum duration of location updating was no more than 15 seconds. The results showed that the presence status of the equipment in each room can be correctly transmitted to the web server if the equipment is within the tracking area of the node.

These findings indicate that the system could be applied in healthcare to track patients, employees, medical equipment, samples, and prescriptions in real-time. The utilization of RTLS can help to optimize patient flow, reduce wait times, and improve the efficiency of medical services. While additional access points may increase the cost of ownership, BLE-based RTLS offers a promising, low-cost option with scalability and high accuracy for proximity tracking applications in the healthcare industry. The widespread use of BLE in mobile and wearable devices further supports the adoption of BLE-based RTLS in healthcare.

The development of this location-based service can improve medical treatment processes and reduce equipment absence issues by providing quick access to assets. In emergency situations, the location of assets can also aid in the immediate dispatch of assistance to patients and medical professionals.

4. ACKNOWLEDGEMENT

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