WiFi and BLE-Based Indoor Localization System

Problem Statement

GPS has long been the standard for outdoor navigation and tracking. However, indoor localization is equally as important, especially in environments like airports where navigation can be challenging. Traditional GPS is ineffective indoors due to high error rates and signal attenuation. To address this, wireless technologies such as RFID, Wi-Fi, and Bluetooth have been developed for indoor positioning. Our project aims to simulate indoor localization using low-power systems, focusing on Bluetooth Low Energy (BLE) and WiFi. BLE is optimized for short-range, high-efficiency communication, making it suitable for localized tracking. In contrast, WiFi is much higher power, and implements more complex protocols. We plan on comparing positioning findings between BLE and WiFi, to understand the tradeoffs of complexity and power on positioning accuracy.

Description

We plan to set up a system of three positioning nodes which attempt to locate a target note. All nodes can be any WiFi / BLE capable device; we plan on using ESP32 (specifically the ESP32-DevKitC prototype board) for the positioning nodes, and a computer running macOS for the target node. The chosen ESP32 has both WiFi and BLE capabilities, can transmit both simultaneously, and allows for programmable transmit power for both technologies. WiFi and BLE positioning will be computed via the three-borders method (TBP)[1] using Received Signal Strength Indicator (RSSI)[2].

A sample 8m x 8m 'room' will be used to perform the experiments. We will perform all experiments with and without line of sight (LOS, NLOS) between each positioning node and the target node, and in discrete measurement. Data from each node will be logged locally onto an SD card, and position values will be computed after the fact. The WiFi and BLE trials will be performed simultaneously to minimize cross-trial error.

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[1] D. Permadi, "Comparison of Three Border Positioning (TBP) and Least Square Estimation (LSE) Algorithm Towards Indoor Positioning System (IPS)" *COMNETSAT 2023*.
https://www.researchgate.net/publication/378050173_Comparison_of_Three_Border_Positioning_TBP_and_Least_Square_Estimation_LSE_Algorithm_Towards_Indoor_Positioning_System_IPS

[2] Li, G.; Geng, E.; Ye, Z.; Xu, Y.; Lin, J.; Pang, Y. "Indoor Positioning Algorithm Based on the Improved RSSI Distance Model." *Sensors 2018*, 18, 2820. https://doi.org/10.3390/s18092820

Deliverables

We plan on finding the calculated position of the target node in different (discrete) locations. In the process we will generate data and a graphical representation of the estimated position in 2D space of the target node, the real (ground truth) position of the target node, and the error between the calculated and real position, across both the WiFi and BLE trials. We can then compare the errors of WiFi and BLE positioning as a function of both a) x and y and b) average distance to a positioning node. This will help us compare the accuracy of WiFi and BLE positioning across these independent variables, and create application recommendations for each protocol depending on the needs of the application. We will also compare LOS and NLOS data within each and across the two technologies, to provide similar recommendations.

Milestones

Date	Milestone
3/10/2025	BOM + proposal
3/17/2025	Finalize setup design, begin writing TBP algorithm
3/24/2025	Write the TBP algorithm for ESP
4/7/2025	Perform experiments and collect data
4/14/2025	Analyze data and generate visualisations
4/21/2025	Write report and make application recommendations

Project Requirements

Hardware

Item	Quantity	Price per item	Subtotal	Source
ESP32	3	$11.00	$33.00	Amazon
Power Supply	3	$9.80	$29.40	Amazon
5.5x2.1mm Plug Adapter	1	$7.59	$7.59	Amazon
breadboard	--	--	--	IDeATe / TechSpark

Software

- Development environment for microcontroller programming
- Code implementing TBP algorithm using RSSI data for positioning
- Data analysis tools (e.g. Python)

Risks

When performing indoor localization using the aforementioned methods, we consider potential risks that can affect the accuracy and reliability of our project. One major risk would be signal interference for both NLOS and LOS. In indoor environments, WiFi and BLE signals can be impacted by walls, furniture or other devices, which may lead to multipath effects causing fluctuations in RSSI values. This will make it difficult to accurately estimate distances and determine the position of the target node. To control for this, we will be conducting several controlled trials in both LOS and NLOS conditions and ensuring a relatively consistent test environment for our simulation with minimal external wireless interference. It is important to note that this risk is built into this localization approach, so any implementation of this technique in the wild will face similar challenges. As a result, we will have to simultaneously attempt to control for this noise, while also capturing and reporting on its effects. Another potential risk is the limited space we will be measuring across. Since BLE is a low-power technology, it is possible that much of the difference between positioning accuracy across WiFi and BLE will be in the area of greater distance from the positioning nodes, which we will not be able to capture. If we see signs that this may be the case we might modify the experiment to include longer distance measurements, or simply report on this trend in our limited experimental capabilities.