Indoor Location Architecture to Achieve a Frictionless User Experience

Nicolas Velasquez* and Diego Mendez*

*Department of Electronics Engineering - Pontificia Universidad Javeriana, Bogota, Colombia
Email: nicolasvelasquez@javeriana.edu.co - diego-mendez@javeriana.edu.co

***Abstract*—Indoor location of people is a wide studied topic as it is a powerful tool that can be used to many tasks like helping to navigate better inside a large space like an airport, understanding better the trajectories of people on a certain place, or tailoring marketing strategies depending on the current location of an individual. Currently, indoor location using Bluetooth low energy is very used because of the low power consume and the low prices of the beacons. But an issue of usability is still present and is that every space need a new app, and that discourage the users to use the system. This paper describes the work in progress of a distributed indoor location system using BLE that migrates the processing and calibration requirements from the smartphone to external hardware and the cloud so there is only one free application that can handle all the location based services of every place. We first present the architecture of the system and then show the implementation of 5 BLE nodes with Ultra Wide Band technology that allows a more accurate location and is used as a reference for the calibration of the Bluetooth system.**

I. INTRODUCTION

Global navigation satellite systems (GNSS) like GPS and GLONASS has changed the way people locate around the world. The issue of GNSS at its beginnings was that it was not accessible for a regular pedestrian, but it needed a specific hardware, usually bulky, which cost was not for everyone. That barrier was surpass when smartphones became available and apps like Google Maps allowed common pedestrians to locate the nearest coffee shop. Even though GNSS are a very versatile technology it presents limitations when the line of sigh with the sky is limited, like in very cloudy days or in indoor locations. To address the latest issue, several techniques called indoor positioning systems (IPS) are being research, developed and used. Some of the techniques used are magnetic positioning, that relies on the distortion of the magnetic fields inside buildings; inertial measurements using accelerometers and gyroscopes to know the movement of the person; WiFi signals to calculate the location and Bluetooth Low Energy (BLE) calculating distances using the strength of the signal of prelocated beacons [1].

These techniques have advantages and disadvantages and for regular people (with smartphones) the most practical are the ones using WiFi or BLE beacons, as these 2 technology are present is almost every new smartphone. In this research we focused on the BLE beacon based location, as several companies like Estimote[2] or Aruba[3] promotes its use and Google relies on beacons to achieve what they called Physical Web[4], therefore it has a growing market. Analyzing this technique it was found that there is a major barrier for regular people to use this technology, that is not based on the technical characteristics of it or the price, but the user experience. The problem is that for every location an app is needed (as the app has the calibration file to be able to locate the smartphone) and as there are several beacon providers and software companies that develop this system is very likely that the places' owners hired different companies and have different apps. In user experience context, the friction is everything that makes harder to use a digital technology[5]. If a person needs to install a new app every time they want to use a beacon based system, they would be very discouraged to do so unless they are in great need. An analogy for that is that every time somebody needs to find a coffee shop or a store in an unknown place they had to download a new app, therefore it would be easier to ask somebody. But they could miss additional information found in the app like open times, if they have parking lots, or how the store is rated. Based on that, the objective of this work is to find a frictionless way to use the IPS using BLE, not having to install an app for every location but being like Google maps that works in every part of the globe. The contribution of our work is proposing an architecture of a distributed system that allows a cloud based solution using a royalty-free app so that using a location service would be as easy as opening a new web page. The remainder of this paper is divided into 4 sections. First related works are being presented, then the system architecture is described followed by the implementation done, including hardware, mobile application and cloud service. In the final section the conclusions and ongoing work are presented.

II. RELATED WORK

There are many companies that are working on improving indoor location using BLE. One of the most important is Estimote[2], that offers a wide variety of BLE beacons not only to achieve an indoor location system but to integrate tools for enabling other location based services like showing advertisements on TVs depending on the proximity. Additionally they have various software tools that facilitates the making of a new location app taking in count the design of the app and the functionality, but the issue is that every location would result in a different app. A company that partially solves this is Aruba Networks[3], that also provides the hardware and software needed for this kind of developing. They have an app called AppViewer where a user can open any Aruba-based development and see the map. With this approach there is only 1 app needed to view any location but the issue is that this app is a temporary solution to test a new location development as publishing a new app on Android and specially on iOS can be tedious and take time. Even though with AppViewer every location system can be seen from just 1 app, this only works as a temporary preview while the main app is uploaded to the corresponding store.

III. PROPOSED ARCHITECTURE

To achieve a frictionless experience, the objective is to create an architecture with a royalty-free framework that the software developers can use to program the location and location based services (LBS) of a certain store or place. On Figure 1 the system can be seen and the elements that compose it are:

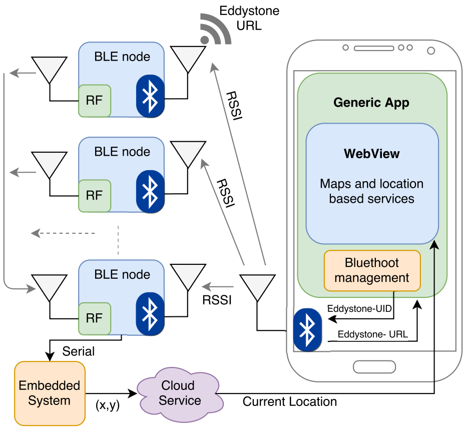

Figure 1: System Architecture.

- **BLE nodes:** This nodes have several functions and roles in the system. First they have to be able to send Eddystone-URL signals advertising the URL related with that particular place. This URL is a deep link that opens the generic application and the parameters of the link opens the corresponding WebPage with the map of the place. Another function is to receive the Eddystone-UID messages sent from the smartphone and extract the RSSI, to calculate the current position of the phone. After that they have to send that information to a main node through a RF communication link. Finally the main node has to gather all the information of the other nodes and send it through a serial link to an embedded system.
- **Embedded System:** This system gathers the RSSI information of the nodes and calculates the current location of the smartphone. After that it sends the information to a cloud service.
- **Cloud Service:** The cloud host all maps and location based services as webpages (WebApps) and also sends the locations received by the embedded systems to the corresponding smartphone.
- **Generic App:** It has that name because the goal is that it works with every location service or map, and the user only have to download it once. When the cellphone receives the Eddystone-URL message, the app opens, activates the bluetooth module and start sending Eddystone-UID type of messages to be identify. Besides that, it opens a WebView[6], and loads the WebApp of the corresponding place. It also notifies the cloud service the UID used so it is able to send the location to the right phone.

A. Pros and Cons of the system

The system proposed has the advantage that any configuration of the map, the location based services, or calibration of the system is located on the cloud and the embedded system, therefore it can be updated even if the user does not update the app. The other advantage is that as the system propose a free-in-any-way app, the user does not have to download a new app for almost each new place with LBS. This decreases the friction of using these technologies and new forms of marketing or services can be achieved. On the other hand, one problem of the system is that it relies on the connectivity of the embedded system and the smartphone to the Internet. If some of this elements have a very high latency sending or receiving the data the user experience can be heavily affected.

IV. IMPLEMENTATION

A. Hardware

The implementation of this system was made with 2 boards, the OnePos module that was design for this project as the BLE node, and the Agriculture Computer system, from the company Agrum[7], that has all the components needed for the embedded system and was already used by the authors in previous works.

1) OnePos: The BLE nodes, called OnePos, are a set of 5 nodes manufactured for this implementation. In Figure 2 the block diagram of the system can be seen. This nodes are designed to work with any kind of battery between 1.5V to 5.5V. A DC/DC converter was used for this purpose and the system voltage is 3.3V. The microcontroller used is an ATxmega32a4u[8] from Atmel that has all the components needed for this development and it is a low power consume microcontroller. For the BLE module, the RN4870[9] chip from Microchip was used. It has several functions accessible via ASCII commands and another advantage is that it has the antenna embedded, accelerating the design process. For the serial communication with the embedded system, the protocol RS485 was used as it allows communication at long distances (up to 1200m) and several nodes can be connected to the same line. Besides that, the system has an USB port intended for variables configurations, debug and programming. 4 LEDs, 2 buttons and several pins from the MCU were exposed for prototyping. Finally, for the RF link, the Ultra Wide Band (UWB) module DWM1000[10] from DecaWave was selected. It serves 2 main purposes:

1) The communication between nodes.
2) This modules are designed for location between the same modules with a resolution of +-10cm. Having this resolution it serves as a reference system to calibrate the location using the BLE RSSI.

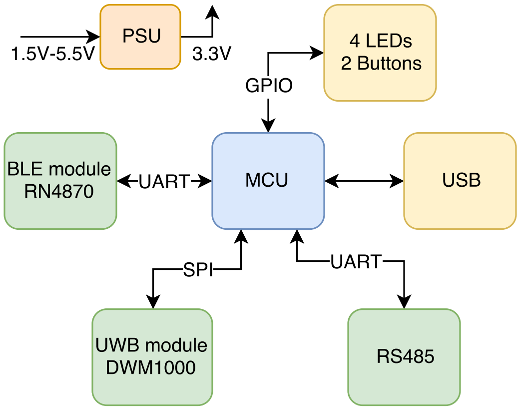

Figure 2: OnePos block diagram.

The 3D view of the final design and one of the nodes assembled and with the enclosure made in laser cut with acrylic can be seen in Figure 3.

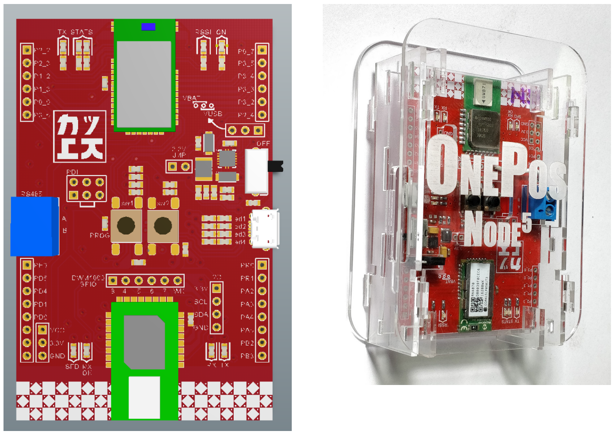

Figure 3: Render of the PCB design (left) and final prototype (right).

Table I: Calibration of UWB for each node. Each unit represents 15,65 picoseconds

	RX antenna Delay	TX antenna delay
Node 1	18405	14461
Node 2	18420	14472
Node 3	18440	14489
Node 4	18398	14453
Node 5	18421	14474

For testing, 1 node was programmed as base node, that is the one in charge of gathering all the information of the other nodes, or support nodes. There are 3 support nodes and 1 node programed as location node, that is a mobile node used to calculate the real position during the calibration of the RSSI. As the reference point, that is obtained with the UWB system, is very important to have a good BLE calibration, several steps were done to assure this. First the UWB nodes were calibrated. The parameters that are calibrated are the delay in the antenna when sending and receiving new data. For doing so, the steps in [10] were followed that consist in putting 3 nodes in an equilateral triangle with a known distance and run the measuring program of the modules to have the 6 distances between the nodes. This step is done setting the RX and TX delay of the antennas to zero. After that an optimization algorithm is run in order to find the parameters per module that best fits the real distances. This was done 3 times with node 1, 2 and 5, and 3 times with nodes 3, 4 and 5. The results are shown in table I

2) *Embedded System:*

The system Agriculture Computer from Agrum was used. This board contains digital inputs, digital outputs, 4-20mA reader, ADC inputs, GPS and GPRS communication and it has a Nanopi NEO Air board from FriendlyElec[11]. The main characteristics of this board are:

- CPU: Allwinner H3, Cortex-A7 quad-core up to 1.2GHz.
- Memory: 512MB of DDR3 RAM
- Storage: 8GB eMMC
- Wifi and Bluetooth connectivity
- Embedded linux: Ubuntu Core

This Board contains all the components needed to process the RSSI information and transform it into x and y points. The programming is being made in python and sent to the cloud service using MQTT protocol.

Inside this board the calculations of the reference location, using the UWB information, and the estimated location, based on the BLE RSSI takes place. For the reference location, the distances between the location nodes and the other nodes are obtained. If the error of the distances were 0, a trilateration formula could be used to locate the reference point, but as an error is added in each distance an iterative algorithm, nonlinear least squares, are used to obtain the best point x_0 and

Table II: Results of location algorithm with calibrated and uncalibrated UWB node

	X (cm)	Y (cm)	Error X (cm)	Error Y (cm)
Calibrated	70.751	81.746	4.248	6.746
Uncalibrated	35.51	103.82	38.48	28.826

y_0 that fits the next formula for all the 4 distances.

$$d = norm\left(\begin{pmatrix} x \\ y \end{pmatrix} - \begin{pmatrix} x_0 \\ y_0 \end{pmatrix}\right) \tag{1}$$

where d is the distance of the nodes and the location node, and x, y are the location of the support and base nodes. For testing this algorithm and to see the impact of the UWB calibration in the system the follow experiment was made: The support nodes and the base node were put in each corner of a square with 1.5m per side. In the middle of the square, the location node was put and then all the system was turned on to measure the distance. The results are in table II. For the uncalibrated system, the values of RX and TX antenna delay were 16438 as suggested on the manual. The real location of the node was 75cm in x and 75cm in y.

B. Mobile App

The architecture of the mobile app can be seen on the Figure 1. Right now the app is being developed in android, as it has less restrictions than iOS when working with Bluetooth. Meanwhile for early test of the system, the app Beacon Simulator is being used. It allows the simulation of a BLE beacon, using the Eddystone-UID protocol and changing parameters like the ID and the strength of transmission.

C. Cloud Service

For the cloud service, the system RedPanda was used. This is a cloud implementation made partially by the authors and used in previous IoT projects. It receives MQTT messages with JSON structure, process them and store the values on its database. For each project a front end part has to be design and for this implementation its under development. More information about RedPanda can be found in [12].

V. CONCLUSION AND ONGOING WORK

The preliminary results of the reference point with the calibrated UWB nodes present a very accurate measurements that is located in the promised range of the company that made the modules, DecaWave, to be +-10cm. This accuracy allow us to have a very good reference point for the later calibration of the BLE signals. Its also important to notice the impact of a proper calibration of the UWB module to obtain a solid reference of the later steps.

The next steps of the project is to have a fully functional mobile app and and cloud front-end to visualize the location. Several algorithms will be tested for the location of the smartphone using RSSI and those results will be compare with regular solutions to see the behavior of them. Finally, tests with people will be made to see if the proposed solution decrease the friction of the user experience.

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