Indoor Navigation and Positioning Using Low Energy Bluetooth

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ABSTRACT

Currently, mobile phones are the primary method of navigation. However, indoor positioning and navigation poses a unique problem because the GPS satellites normally used to navigate outdoors have limited use indoors. One solution is using Wifi access points as anchors, measuring the signal strength and calculating position using trilateration. Indeed there are companies today that provide the framework for such an implementation. However there are certain disadvantages with using Wifi, namely that there is no context to the position. A location must be associated with a particular context separately.

This project aims to address this issue by implementing a different method of indoor positioning, one that uses the recently released Bluetooth 4.0. With the new APIs released by Google and Apple in the past few months, we can now use Bluetooth devices to act as anchors. One key feature of Bluetooth 4.0 is the communication between devices that is allowed; this will allow us to enrich and contextualize position. This peer to peer messaging opens up many possibilities, ranging from applications in shopping malls to emergency response teams.

1. INTRODUCTION

With the widespread availability of the smart phone, individual navigation has been refined such that a user can navigate to and from a particular address. The standard used today for outdoor navigation relies on GPS satellites to track the device location. GPS is generally not well suited for indoor use for two reasons - 1. GPS does not provide a high level of accuracy, and 2. the GPS signal breaks down indoors. So rather than using GPS satellites, indoor navigation and positioning has been accomplished largely through using networks of nearby "anchors" that have a static, known position. Most commonly used anchors today are Wifi networks. The device detects a Wifi network with a unique ID; with the wifi access point, we can triangulate the exact position of the device. Indeed there are several existing companies that will set up the necessary pieces to allow for step by step navigation through a shopping mall or a departmental store.[1]

Google and Apple have both introduced a technology called Low Energy Bluetooth, also known as BLE or Bluetooth Smart, that introduces a new way to navigate indoors. Apple in their recent release of iOS7 has included an API called iBeacon, that will use BLE extensively for the purpose of precise geolocation[1]. Any "beacon" that is set up will be available for general iPhone users to navigate with; what makes this technology remarkable is that BLE uses very little energy, as the name suggests, has considerable range, especially compared to Wifi networks, and most importantly, beacons can be setup anywhere. Any iPhone device can be set as a beacon, and devices designed specifically for the use of becaons can be purchased. Similarily, Android in their most recent OS release 4.3 has implemented BLE as well, providing a well defined API[5] to develop upon. As of the writing of this paper, only the most recent devices even have BLE hardware built in, and on top of that only select devices have the OS that provides a native API to utilize BLE, so suffice it to say BLE as a method of navigation is still in its early stages.

A method of adding context to position has many important use cases. One example is in emergency response situations, where location awareness is of utmost importance. "Existing indoor navigation solutions usually rely on pre-installed sensor networks, whereas emergency agents are interested in fully auto-deployable systems"[8]. Indeed the current Wifi implementation requires Wifi access points, a data service that computes location, and a location specific context in order to work correctly. Although this might be feasible for shopping malls and departmental stores, it does not have much use in a situation where there is no predefined context. With BLE, all we need to do is drop a few anchors to detect devices and have the devices transmit small pieces of data, such as an ID, and we can successfully track the location.

Existing indoor navigation systems have the problem of high setup costs and a lack of contextual awareness. Our project will address this issue by using the aforementioned BLE technology. "The GATT profile is a general specification for sending and receiving short pieces of data known as 'attributes' over an LE link. All current Low Energy application profiles are based on GATT" [**?**]. Using the GATT profile, contextual awareness is now possible to add anywhere. Important to note here is that all current Low Energy application profiles are based on GATT - this means any device can act as an anchor, receiving and sending pieces of data, eliminating the lengthy and costly setup of wifi access points and a framework to manage them.

In order to accomplish this implementation, we will need to extensively test the capabilites of BLE. We need to be

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[1]See meridianapps.com and senionlab.com

familiar with the range and limitations of the hardware; the range and strength of the bluetooth signal must be tested. Empirical tests on older versions of Bluetooth do exist, and we will use this as a benchmark and starting point for our research and testing[3].

2. RELATED WORK

Fully functional Indoor navigation apps, although a relatively recent invention, have been implemented before. For example, the company SenionLab provides a way for third parties to integrate an indoor navigation API to their existing application[7][2]. The API includes location based advertising, allowing for companies to send tailored advertisements to the customers that walk by their store, location analytics, the ability to gather data on user behavior and most importantly, a fully functional step by step navigation system at the granular level. However, there are some shortcomings that current indoor navigation apps have in common. Most widespread is the dependence on existing Wifi access points as the anchors. Although this allows for the application to pinpoint the exact location of the device and track it as it moves, it does not provide environmental awareness. These Wifi based implementations do not carry any data about a particular location, such as whether a store carries a particular product, or if the store is currently having a sale. A fundamental assumption is being made in this case, that is, customers already know *where they want to go*, rather than *what they want to do*, and this is the fundamental issue we seek to resolve.

We also cannot forget the costs of implementing a framework that uses wifi access points. Wifi needs to be set up well in advanced, and a data service that calculates position must be implemented. Finally, Wifi has associated costs that the user must invest in, such as monthly internet charges, maintenance, and an app for users to download so that they any of the positioning makes sense.

With BLE we no longer have to make this assumption. BLE signal transmitters are low cost: for example, for Apple's iBeacon, "beacons" as they're called, cost as little as 30 or 40 dollars. As their name suggests, BLE uses little energy. Most important of all, they can be ubiquitous - a shopping mall where every store has a proximity sensor, or an anchor, and we can achieve much more granularity than Wifi access points could ever provide. With this granularity comes enriched data - anchors no longer just provide a specific location, they can provide specialized promotions, specific directions, and most important for our purposes, personalized recommendations.[6] This means that a customer, with his/her list of shopping needs can navigate through a shopping mall or departmental store and find detailed offers based on what he/she would like to purchase.

This introduces a concept that may be highly relevant to this discussion; the role that proximity sensing plays in the behavior of our application. The most common use case for iBeacon in particular that has been explored in most detail is trigger based proximity marketing that such precise geofencing provides. Applications range from simple coupon pushes to nearby devices, to the more complex interactive tours that would involve actions triggered by a nearby device. While the proximity marketing capabilities of BLE are hard to ignore, we will focus mostly on navigation, with the goal of enriching the data collected as much as possible. Advertisement campaigns using BLE geofencing is out of the scope of this project.

Indoor navigation using older Bluetooth technology has also been implemented. "The system compares the signal strengths of surrounding Bluetooth devices to a database of measurements taken across the indoor area, in order to estimate the user's position. Through an evaluation of the system, an accuracy of approximately 1.5 meters has been obtained."[2]. Even using the older bluetooth technology, an accuracy of 1.5 meters is possible; we will use this as the goal for our implementation.

3. PROJECT PROPOSAL

There are two needs that this project aims to address. First, the existing indoor navigation apps do not necessarily take full advantage of the existing technology. Contextual awareness is a common weakness that these apps suffer from; current apps rely mostly on wifi access points to pinpoint position, and all other data is built upon this position. The app must know what store is currently at a particular coordinate in order to infer any additional information about the location. With BLE technology, we can enrich the data carried by the "anchors" that indoor navigation implementations rely on with contextual awareness.

Second, due to the relative lack of contextual awareness, it is difficult to calculate an optimal shopping route given the wishes of the shopper. Today, most product search apps work by calculating the exact position of the product in question, and locating through the wifi access point. However, we now have more precise geofencing methods that allow for more complex searches. Instead of having to search for a specific product, the customer can receive personalized recommendations based on the list of products he/she has listed to purchase as he/she navigates through the store.

Using BLE technology to gather richer data about geolocation, we will build an app that allows a user to set a few BLE devices as anchors and then track location of other devices using the app, and some information that pertains to each of device (such as user id)

3.1 Anticipated Approach

Three main modules must be put into place. First, the central data processing unit will store all the relevant data pertaining to the anchors. For example, in the shopping mall implementation, the product catalog and other information about the store would be associated with a partcular anchor, and then stored in the central data unit. The central data service will then communicate with device, alerting it for example when an item in the shopping list is nearby. It will also store the exact location of each anchor, which it will use to calculate the position of a device when it comes into range of any anchor. The ideal structure that handles the central data service would be one that can parse different pieces of data.

Finally, the device to device communication must be well defined. When a device enters the range of an anchor, the anchor should send over to the central data service information about itself (for example, what products they currently have in stock) as well as the location of the nearby device. Communication between devices is also key; each de-

[2]SenionLab: The website contains a splendid video demonstrating the capabilities of their turn by turn navigation http://senionlab.com

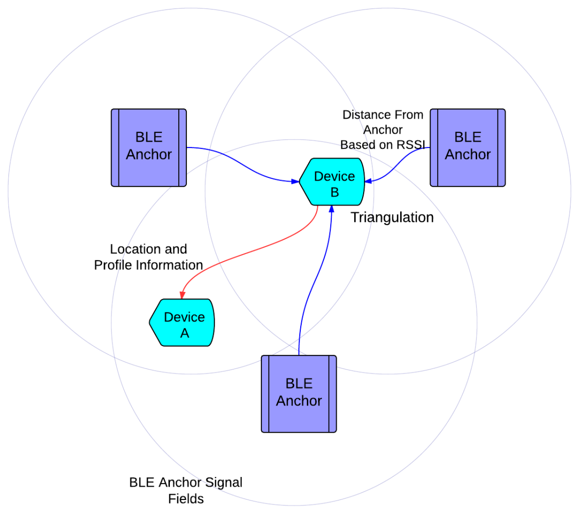

Figure 1: Anticipated Approach to BLE Navigation

vice must be able to transmit profile information to another device reliably.

The method we will use to caclulate location will be based of the Received Signal Strength Indicator (RSSI) that is associated with Bluetooth signal transmission.

The use case we will base our project on is day to day use with friends. Those who have the app downloaded will be able to go into a room with a bluetooth device already set as an anchor, and be able to see which friends are in the room, and how to find them. The key features will be implemented through this use case, and the app can then be extended to handle more complex cases, such as shopping mall navigation or emergency response. First, the anchor should be able to detect the device when it comes into proximity; similarily, the device should recognize the anchor in the room. Once recognized, the anchor will receive location data (RSSI), and some contextual data from the detected device (for our case we will use a user profile that includes name). The anchor will then send that data to our central data service, which will then calculate the position of the device. Then, the central data service will send back information about other devices and their context. Essential here is that each bluetooth "message" holds position data AND contextual data, and it will be transmitted from device to device.

3.2 Technical Challenges

There are two main technical challenges involved with this project. First, we have to build a functional app using fairly new technology, to implement an existing technique for navigaiton. Indoor navigation using BLE is unprecedented as mobile operating systems are just now providing APIs to use BLE as a geofencing tool. BLE itself was introduced in 2006, and it was only merged into the Bluetooth standard in 2010[3]. Even though BLE is in widespread use today, the APIs to utilize BLE are very young

Calculating position using Bluetooth also poses an interesting problem. "For a precise position estimation, the dependence between the distance and the received signal strength has to be determined. Especially in the indoor area, boundary conditions like reflections and wall damping make the use of the equation for the free-field propagation impossible. Therefore, the required calculations of the distances are estimated by an approximation of the Received signal Strength Indicator (RSSI)" [4]. We must use a method to calculate position that has been traditionally applied to older Bluetooth technology to the brand new BLE 4.0. In addition, the new API may make this calculation easier or harder; research and testing will be done on this.

3.3 Evaluation Criteria

A fully functional BLE navigation app is certainly the most basic goal. To demo this, we will be using two devices and an anchor to act as our scenario. The anchor should detect the two devices and successfully send the contextual and RSSI data to the central data service. Then, the data service should calculate the position of all the devices and send back to each of the device its own location, and the location of the other device, along with the user profile associated with the other device. In the end state, the two devices should know where they are, who the other device is, and where the other device is. Note additionally that this should happen in real time; if device B moves, the user of the device A should see the movement.

As of the writing of this proposal, no BLE navigation applications are currently in widespread or mainstream use. During the course of this project, that may change, and various BLE navigation applications may very well arise. We can compare results from these apps should that happen. Also, since Android is currently the only operating system who has opened to the public their BLE API, we will be using Android devices to test all of this, and we will program the app for use on Android.

4. RESEARCH TIMELINE

Since this project is much more focused on implementation over research, most of the time will be devoted to building features of the end product. We will use agile processes (specifically, SCRUM with elements of extreme programming when meeting with our advisor) to complete our project.

The general format will follow two week sprint cycles, where a fully functional feature will be implemented by the end of each cycle. In any given cycle, a feature will be implemented, tested, and refactored. Of course in the early stages, the emphasis will be on research

- ALREADY COMPLETED: Preliminary reading.
- PRIOR-TO THANKSGIVING : Research on Bluetooth hardware, particularly how a solution will be implemented given the resources. Formulate the framework of the app - what platform will it be built on, what structures will be needed
- PRIOR-TO CHRISTMAS : Have an API that fully implements BLE navigation - Detecting BLE transmitters is the main feature to accomplish.
- COMPLETION TASKS : Verify implementation is bug-free. Conduct accuracy testing. Complete write-up.

[3]bluetooth.com

- IF THERE'S TIME : Make the API relatively user/app friendly - ideally it needs to be lightweight (we do not want BLE navigation consuming large amounts of resources), and easy to use

Most of the research will involve the bluetooth hardware specifications, that is, the signal strength of BLE and the computational power of the everyday device.

5. REFERENCES

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[7] SenionLab, Meridian. `http://senionlab.com` and `http://meridianapps.com`. SenionLab and Meridian both offer wifi based indoor navigation APIs to integrate with existing applications.

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