ECE 480: Senior Design
Design Team 6

Bluetooth Low Energy Beacon
Proposal
Executive Summary

Navigating a large environment like the Michigan State University campus is a challenge for the blind and visually-impaired. This project’s goal is to design a Bluetooth Low Energy (BLE) beacon, based on Apple’s iBeacon standard, for assistive navigation. The primary objective is a low cost BLE beacon to allow large scale deployment across the Michigan State University campus. Three designs were investigated, each relying on different Bluetooth Low Energy chips (TI’s cc2540, Bluegiga’s BLE112, and Nordic Semiconductor’s nRF8001). The TI cc2540 was selected for the proposed design. Mobile applications for Apple’s iOS and Google’s Android operating systems will also be developed to demonstrate the functionality of the BLE beacons.
# Table of Contents

1. Introduction..................................................................................................................3
2. Background..................................................................................................................3
3. Design Objectives........................................................................................................5
4. Conceptual Design Description....................................................................................5
5. Conceptual Design Rankings.......................................................................................6
6. Proposed Solution........................................................................................................8
7. Risk Analysis...............................................................................................................9
8. Project Management Plan...........................................................................................9
9. Budget..........................................................................................................................10
10. References..................................................................................................................11
1. Introduction

The Michigan State University East Lansing campus consists of 538 buildings spread out over 8.125 square miles. Navigating the campus is a daunting task, even for normally-sighted people. The challenge for blind and visually-impaired members of the Michigan State community is significantly greater while they are becoming familiar with the campus. Twenty minute class change intervals are inadequate for blind students and the risks of injury to anyone are increased by rushing through unfamiliar locations.

The Research Center for Persons with Disabilities at Michigan State University has proposed to use a new interactive positioning interface, a Bluetooth Low Energy (BLE) beacon to assist blind people in navigating across campus. The beacons can be set up around campus and will be able to communicate with students via BLE equipped smartphones. Using BLE beacons provides a low cost and low power navigation solution. Each beacon is able to send a signal that approximates a beacon’s distance to BLE equipped smartphones that are within range. Once a device receives the signal, an alert can be triggered to give the user a notification or location information. Installing these beacons at building entrances, exits, in hallways, and inside rooms will provide a highly accurate navigation system.

The goal of this project is to create a BLE beacon design that is low cost and able to communicate with Apple iDevices. The proposed design will use a Texas Instrument cc2450 BLE chip and will be tested against other designs with different BLE chips. The main focus on application development will be on the iPhone because Apple has already released an application programming interface (API) for BLE beacons. An application for the iPhone will be created with accessibility options for blind users. An application for Android will also be created demonstrating a more universal use of such beacons.

2. Background

BLE beacons communicate by broadcasting a packet of data at an interval ranging from 20 milliseconds to 10 seconds using the spectrum range of 2.4-2.4835 GHz. Unlike classic Bluetooth, BLE allows the signal to be broadcast on a range of profiles that can be specified to benefit in a particular application. BLE uses minimal power to broadcast and receive signals allowing extended use of wireless devices without reducing battery life. A device will determine the distance from the beacon based on the signal strength. Apple’s operating system (iOS) for iPhones and iPads has BLE beacon support built in. Google’s Android operating system has not yet implemented BLE beacon support.
There are several BLE beacons currently on the market, however the cost of these beacons is too high for large scale deployment. One example is the Estimote Beacon which retails for $99 per beacon. There is also a Raspberry Pi based beacon which would cost approximately $40, however software for it is not fully developed. Designs like the Raspberry Pi based beacon add functionality which is not necessary since this project’s objective is to design a low cost beacon with just the necessary components to accomplish assistive navigation.
3. Design Objectives

This project’s goal is to design a Bluetooth Low Energy based beacon to be used for assistive navigation. This beacon will need to be compatible with Apple’s proprietary iBeacon technology; the beacon must work with Apple’s current iBeacon infrastructure and software APIs. Based on component prices, the cost of the beacon should be less than $20 per beacon which would be suitable for campus wide deployment. The beacons must be resistant to tampering and reprogramming as these could disrupt the functionality of the location identification software. Power will be provided via AC outlets located near the building entrances and exits. Development of mobile applications for iOS and android devices is also required to demonstrate the functionality of the beacons.

![Diagram 2: Function Analysis System Technique Diagram](image)

4. Conceptual Design Description

Three possible hardware designs have been investigated as possible solutions to the design problem. Each of the designs is based on a different BLE chip. Similar support hardware is necessary to implement the three chips, the differences among the designs are largely cost of the BLE chips and what functionality they have built into them.

- Design one: Texas Instruments based design
  - This design uses a TI cc2540 BLE chip to implement the Bluetooth functionality. The TI cc2530 is a system on a chip (SoC), meaning no external
microcontroller will be needed. The cc2540 BLE chip does need an external antenna to operate.

- Design two: Bluegiga based design
  - This design uses a Bluegiga BLE112 BLE module designed to make implementing Bluetooth functionality straightforward. The BLE112 has a built-in antenna and is based on the TI cc2540 SoC BLE chip. The BLE112 requires the fewest number of external components, but is the highest cost BLE chip.

- Design three: Nordic Semiconductor based design
  - This design is based on the Nordic Semiconductor nRF8001 BLE chip. The nRF8001 is the least feature rich of the possible BLE chips as it requires both an external microcontroller and an external antenna. This chip’s main advantage is its minimal cost even at low volumes.

The software design will focus on demonstrating the location identification functionality of the BLE beacons. Apple’s iBeacon API will be used to implement the iOS demonstration application. Google’s Android operating system does not currently offer a native BLE beacon API, but an application to demonstrate future functionality will be developed.

5. Conceptual Design Rankings

To decide between the three possible designs, the major design criteria of cost, size, and security are ranked by importance on a scale of one to five. Each of the designs are then ranked on how well they meet the design criterias on a one, three, nine scale. These rankings are used to compute a final value which indicates the desirability of each design.

<table>
<thead>
<tr>
<th>Engineering Criteria</th>
<th>Importance</th>
<th>Bluegiga module design</th>
<th>TI chip design</th>
<th>Nordic chip design</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>5</td>
<td>3</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>Size</td>
<td>1</td>
<td>9</td>
<td>9</td>
<td>3</td>
</tr>
<tr>
<td>Security</td>
<td>3</td>
<td>9</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>Total</td>
<td>51</td>
<td>81</td>
<td>75</td>
<td></td>
</tr>
</tbody>
</table>

Table 1: Solution Selection Matrix

According to the table 1, the total score of three designs conclude that the best choice for the product would be the TI chip design. Its major advantage would be its low cost, size,
and similar performance which would match other two design. However, the scores of the Nordic and TI designs are relatively close.

The feasible designs are ranked based on engineering criteria of cost, size, security, development time, and manufacturability. The importance of the criteria is rated on a scale of one to five. Then the designs are rated based on how well they meet the criteria on a one, three, nine scale.

<table>
<thead>
<tr>
<th>Engineering Criteria</th>
<th>Importance</th>
<th>TI chip design</th>
<th>Nordic chip design</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>5</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>Size</td>
<td>1</td>
<td>9</td>
<td>3</td>
</tr>
<tr>
<td>Security</td>
<td>3</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>Development time</td>
<td>5</td>
<td>9</td>
<td>3</td>
</tr>
<tr>
<td>Manufacture</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>135</strong></td>
<td></td>
<td><strong>99</strong></td>
</tr>
</tbody>
</table>

Table 2: Feasible Design Matrix

Table 2 indicates that the TI design is the most feasible design. The TI based design requires less development time because the Bluegiga module can be used for developing the software and firmware while the hardware for the TI design is being developed. The Bluegiga module uses the TI cc2540, the same programmer as the TI design, and includes a built in antenna. Because the Bluegiga module uses the TI cc2540, the firmware will easily port over to the TI design, allowing parallel development of the TI hardware and firmware.
6. Proposed Solution

To suit the design requirements provided from the RCPD, the TI design has been selected. Initially a prototype beacon has been built using the Bluegiga BLE module because it includes all the necessary components to begin software development. This will allow the group to become familiar with the BLE and the iBeacon protocol while concurrently developing the more complex hardware of the TI design. Another advantage of initially developing with the Bluegiga BLE module is that is uses the TI cc2540 as a BLE chip and the same programming device.

With the TI cc2540 chip, a printed circuit board (PCB) antenna must be developed. This will keep the cost down of the TI design. Because the distance measurement is based on received signal strength, the antenna must be comparable to an iDevice antenna that has a range of roughly 50m.

The beacons need to be secure against having its universally unique identifier (UUID) changed by potential threats. For this reason, the beacons will be limited to broadcasting their signal and will not be modifiable via a Bluetooth connection. The only way to connect
and program the device will be through a wired connection which will also need to be protected by a locked bootloader.

7. Risk Analysis

There are a few risks with the design that must be address during development. The first is Bluetooth connection security. The device needs to prevent any software vulnerabilities that would allow the Bluetooth connection to modify the operation of the beacon. If the beacon’s UUID is altered the module could prevent applications from being able to correctly identify its location. This can be done by disabling data transfer between the beacon and another device. The vulnerability of this type is very high risk as it can compromise the functionality of the entire beacon network.

The second risk is the necessity of designing a PCB antenna to lower the cost of the BLE beacon. The BLE chip from TI needs an external antenna which will need to be designed and produced so that the performance of the beacon is similar to an iDevice.

Lastly, there is moderate risk that the design based around the TI chip is unable to perform at the same level as the Bluegiga. Other groups have already used the Bluegiga BLE112 to implement BLE beacons, but the cost of the Bluegiga design would be significantly higher than the TI or Nordic designs.

8. Project Management Plan

Project work will be broken up into five distinct phases in order to focus the team’s effort on specific tasks. The initial phase required the selection of a BLE chip. During this phase each of the three possible BLE chips were be evaluated based on cost and their ability to duplicate the iBeacon protocol. After a BLE chip was selected, phase two will require the development of initial beacon firmware which will be used for testing further software and hardware elements. Phase three will be dedicated to hardware design, mainly developing a printed circuit board layout, including the design of a printed circuit board based Bluetooth antenna. Phase four will be dedicated to the creation of Android and iOS applications, which will be used to demonstrate the functionality of the beacons. The final phase will be testing and refinement of the hardware and software designs. Testing must insure that the beacon’s have a sufficient signal strength, are secure against tampering, and are compatible with current iBeacon infrastructure. The beacons will be tested inside the MSU engineering building using the iOS and Android applications to confirm their
correct functionality. The beacons will also be compared with iBeacons generated by Apple iDevices to ensure they give accurate distance measurements.

Each team member is responsible for both a technical and non-technical aspect of the project, these are listed in table 3.

<table>
<thead>
<tr>
<th>Team Member</th>
<th>Non-technical Role</th>
<th>Technical Role</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nicholas Blackledge</td>
<td>Manager</td>
<td>PCB Design</td>
</tr>
<tr>
<td>Chunyang Chu</td>
<td>Web Coordinator</td>
<td>iOS Development</td>
</tr>
<tr>
<td>Steven Le</td>
<td>Presentation Preparation</td>
<td>Antenna Design</td>
</tr>
<tr>
<td>Matt Smania</td>
<td>Document Preparation</td>
<td>Android Development</td>
</tr>
<tr>
<td>Bowei Yu</td>
<td>Lab Coordinator</td>
<td>Circuit Design</td>
</tr>
</tbody>
</table>

Table.3: Technical and Non-technical Roles

9. Budget

<table>
<thead>
<tr>
<th>Item</th>
<th>Estimated Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bluetooth Low Energy Chips</td>
<td>$60</td>
</tr>
<tr>
<td>Other electrical components</td>
<td>$70</td>
</tr>
<tr>
<td>Programming / Debug tools</td>
<td>$100</td>
</tr>
<tr>
<td>Three demonstration beacons</td>
<td>$50</td>
</tr>
<tr>
<td>Shipping</td>
<td>$50</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>$330</strong></td>
</tr>
</tbody>
</table>

Table.4: Projected Budget
10. References


s-beacon-is-already-in-almost-200-million-iphones-and-ipads/.

"NRF8001, µBlue, Bluetooth low energy." NRF8001 Bluetooth Low Energy. Nordic Semi
Conductor. 30 Jan. 2014

<http://www.nordicsemi.com/eng/Products/Bluetooth-R-low-energy/nRF8001>.


Jan. 2014


Jan. 2014