

MICHIGAN STATE UNIVERSITY



ECE 480: Senior Design
Design Team 6

Bluetooth Low Energy Beacon
Pre-Proposal

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Executive Summary

Navigating a large environment, like the Michigan State University campus, is a challenge for the blind and visually-challenged. 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 solution to allow large scale deployment across the Michigan State University campus. Three designs will be investigated, each relying on different Bluetooth Low Energy chips (TI's CC2540, Bluegiga's BLE112, and Nordic Semiconductor's nRF8001). Mobile applications for Apple's iOS and Google's Android operating systems will also be developed to demonstrate the functionality of the BLE beacons.

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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-challenged 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 the beacon's distance to BLE equipped smartphone that are within range. Once a device receives the signal an alert can be triggered to give the user a notification or location. Installing these beacons at building entrances or exits, hallways and rooms inside the building will provide a highly accurate navigation system.

The goal of this project is to create one BLE beacon 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 technology. An application for the iPhone will be created with accessibility options for blind users. An application for Android will also be created showing 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. Also, as the name suggests, BLE uses little to no power to broadcast and receive signals allowing extended use of wireless devices. A device will receive the signal, and based on the signal strength will be able to determine the distance from the beacon. The design will consist of passive components, a USB port, an antenna, a microcontroller and most importantly a BLE chip to achieve the goals. Apple's operating system (iOS) for iPhones and iPads now 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. Unlike the Raspberry Pi based design, the project's objective is to design the beacon with just the necessary components to accomplish assistive navigation.

3. Design Objectives

This project's goal is to design a Bluetooth beacon based on the Bluetooth Low Energy technology introduced with Bluetooth version 4.0. This beacon will need to be compatible with Apple's proprietary iBeacon technology; the beacon must be compatible with Apple's current iBeacon infrastructure and software APIs. The cost of the beacon must be less than \$20 per beacon to enable campus wide deployment. 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 to the beacons. Development of mobile applications for iOS and android devices is also required to demonstrate the functionality of the beacons.

4. Conceptual Design Description

Three possible hardware designs are being 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

Engineering Criteria	Importance	Bluegiga module design	TI chip design	Nordic chip design
Cost	5	3	9	9
Size	2	9	9	9
Security	3	9	9	9
Total		60	90	90

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 among the three designs are relatively close, so it would be best to compare the feasibility in order to determine the best design.

Engineering Criteria	Importance	Bluegiga module design	TI chip design	Nordic chip design
Cost	5	3	9	9
Size	2	9	9	9
Security	3	9	9	9
Development time	5	9	9	3

Manufacture	3	9	3	3
Total		132	114	114

Table.2: Feasible Design Matrix

Table 2 indicates that the feasibility of all three designs. The Bluegiga solution has the least development time, but costs are significantly more than the other two solutions. The TI based design has less development time because part of its firmware is similar to the Bluegiga design and it is the most feasible of the selected solutions, although not much more so than the Nordic based design.

6. Proposed Solution

To suit the design requirements provided from the RCPD, the TI design has been selected. Initially a prototype beacon will be built using the Bluegiga BLE module. This will allow the group to become familiar with the BLE and the iBeacon protocol before proceeding with developing the more complex TI and Nordic BLE chips. One advantage of initially developing with the Bluegiga BLE module is that it uses the TI cc2540 as a BLE chip. The focus on the TI CC2540 is a key solution. By developing with the Bluegiga BLE module first, development of another design around the TI cc2540 will be easier and more effective.

With the TI cc2540 chip, a printed circuit board (PCB) antenna will need to be developed. The antenna will need to be comparable to an iDevice antenna that has a range of 50m. This is more important for outdoor beacons around campus, but indoors a range of only 10m is necessary.

Development of a module around the TI cc2540 or Nordic nRF8001 BLE chip will allow the total cost to be lower than a pre-built solution like the Bluegiga module. The Nordic chip, however, will need a microcontroller to operate which could change the cost significantly, depending on the requirements.

The chips need to be secure against having its universally unique identifier (UUID) changed by potential threats. For this reason, the beacons will only be limited to broadcasting their signal and will not allow to be modified 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 addressed through 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 was 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 entire use of the beacon.

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 designs based around the TI and Nordic BLE chips are unable to perform at the same level as the Bluegiga as they have not been tested as thoroughly. 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 will require the selection of a BLE chip. During this phase each of the three possible BLE chips will be evaluated based on cost and their ability to duplicate the iBeacon protocol. After a BLE chip is 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.

9. Budget

Item	Estimated Cost
Bluetooth Low Energy Chips (TI CC2540, BLE 112, nRF8001)	\$40-60
Other electrical components	\$30-70
Programming / Debug tools	\$50-100
Three demonstration beacons	\$30-50
Shipping	\$50

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