BLUETOOTH LOW ENERGY

An Interim Progress Report

Submitted in Partial Fulfillment of the

Requirements of

MAJOR TECHNICAL PROJECT

of

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1 Introduction

Bluetooth Low Energy (BLE) is the new specification of Bluetooth available. It is a new low power consumption technology aimed to transmit small amount of data. In addition to be able to transmit data, BLE can be used to locate things also. The objective of this project was to implement an indoor positioning system based on Bluetooth Low Energy Beacons and the iBeacon protocol by measuring the strength of the emitted signal by a Beacon. The indoor positioning system uses trilateration methods to estimate the position based on distances estimated through modelling the indoor path loss. GPS has taken the world by storm. It is used everywhere varying from personal uses to government related facilities. However, its drawback of position estimation of only outdoor objects makes it non-viable for indoor positioning system namely, the IPS. Several existing techniques and methods are studied and analyzed in this project. This report discusses the result of the work done in development of iBeacons . They have been existing not only now but since past. The biggest analogy is that of a lighthouse guiding the ships. It doesn't see the ships, the ships are the mobile devices. The beacon behave as the lighthouse and they can see it. It is one simple device that just simply send the signal and allows devices to perceive its presence one know he position of the It helps developers to build new generation context aware mobile applications. To build even more tighly integrated softwares and hardwares. A simpe tool that makes it extremely easy to add precise loacation to any iOS application. It is a three step process which takes only few minutes. They have universal unique identifier , major and minor. They are basically platform independent. The essence of my project lies in figuring out the best possible ways in Bluetooth low energy beacons for proximity sensing or locating users inside a large room with ibeacons.. The main goal of this technology is to build proximity and context-based solutions for mobile apps and devices which we would be working on as our future prospects.

1.1 Explore the Case

This article is about why we are building an indoor positioning system.
Due to the maturity in the wireless technology, location-tracking of objects and people in indoor or outdoor environments has received ample attention from researchers lately. There are various methods for identifying and tracking user position such as Cricket[1], Mote Track [2] or GPS [3]. GPS offers a scalable, efficient and cost effective location services that are available to the large public. However, the satellite emitted signals cannot be exploited indoor to effectively determine the location. Due to different environmental characteristics, none of the above methods is used for tracking user in both indoor and outdoor environment using the same sensor device and sensing method. Hence, accurate estimation of location in both environments remains a longstanding difficult task.

1.2 Bluetooth And Bluetooth Low Energy

It is important not to confuse BLE with "classic" Bluetooth; despite falling under the same name, they are entirely different technologies. Bluetooth consumes more power and transmits farther and with more data. It is suited for streaming media such as playing music on Bluetooth speakers or taking a call through a Bluetooth headset.A BLE beacon is a small device – usually powered by battery or USB – that emits a Bluetooth Low Energy signal. A modern smartphone in the vicinity can pick up the signal being emitted by the beacon and gain some insight into its own positioning based on knowledge of the beacon's placement.BLE transmits less data over shorter distances using much less power than Bluetooth. BLE is designed for periodic transfers of very small amounts of data, such as beacons providing proximity in a store or a medical device providing glucose measurements to a doctor's tablet or patient monitor.

1.3 Research Focus

- The purpose of our project is to identify the position of a person or a thing with the help of Beacons (Bluetooth Low Energy)
- For this problem we need to setup an indoor positioning system (IPS) using Bluetooth Low Energy of Beacon devices.
- Bluetooth allows mobile phone devices of all kinds to send data and communication with each other. The same way music is broadcast over the radio, Bluetooth uses short-wavelength radio waves to exchange data over relatively short distance.
- BLE works same as the Bluetooth, but it has a range up to 50 meters - 70 meters and a high battery backup.

2 Objective and scope of the work

The objective of this project is to implement an indoor positioning system based on Bluetooth Low Energy Beacons and the Beacon protocol by measuring the strength of the emitted signal by a beacon. The indoor positioning system uses trilateration methods to estimate the position of an smart devices based on distances estimated through modelling the indoor path loss.

2.1 Issues And Applications

- Currently, there are many examples and ready-made solutions for outdoor positioning, but how does an app determine your exact position indoors?
- For example, an indoor positioning system inside a hospital can help patients find the right wing or navigate to the next procedure without wasting too much time. Not to mention such modern mazes as airports, su-

permarkets, amusement parks, etc. Also, different interactive game apps are getting increasingly popular.

2.2 Uses

While the goal of indoor positioning for some users, notably hospitals and malls, is to provide navigation aid, others want to use indoor positioning to better market to customers, provide just-in-time information via audio for tours, offer video or augmented reality experiences or connect people of interest in proximity to one another. The U.S. Federal Communications Commission hopes to use indoor positioning to provide timelier and more effective emergency services.

2.3 Limitations

It is possible that our project might have fairly critical flaw in the study design reason being that BLE is quite a new technology, there has not much research done in this field. The procedures or methods which which are using are still under research.
While indoor positioning systems can determine location, many need additional information to determine which way a person or object is facing. That can make providing directions or pitching a product in a store more challenging.
Locating a person or device indoors is only half of the solution. For the location to be meaningful for navigation or other purposes, service providers need accurate indoor maps.

3 Product Qualities

Here we list and explore the product qualities considered most relevant for the case, and produce only a list which we consider most relevant and important. The following list present the prioritized product qualities with the motivation for the prioritization.

3.1 Usability – Satisfaction and Effectiveness

The main purpose for developing the product will be to offer the user a general product that would help them to achieve specific goals based on their requirement. In our case we are primarily focusing on mapping the entire campus so that it could be useful for people to easily navigate the campus. Also it is important that the primary users – students, faculty and staff feel satisfied in using this system. This means App should be simple enough as well as reliable(minimum application failure).

3.2 Scalability

Scalability is second most important quality that our product must have. Product should be able to handle a growing amount of work. It should be suitably efficient and practical when the product is used for big scenarios. The system should not fail when the number of users accessing the server through the app increases significantly.

3.3 Maintainability – Modifiability and Modularity

Modifiability is according to ISO 25010 a combination of changeability and stability, which is very vital to the product. It should be easy to implement the possible improvements suggested by users' feedback. According to modularity in ISO 25100, a small change in one discrete component should make minimal change to other components. Parts of the code should therefore be changeable or easily replaced without defect functionality.

4 Team Collaboration Protocol

4.1 Expectations from team members :

We expect that both of us completes our individual work in due time and participates in discussion.

4.2 Constructive Criticism :

We will first appreciate the solution given by other person, try to look at the solution from his viewpoint and if we still need to criticise then indicate the issues with the person's solution in a logical fashion.

4.3 Team only Meetings :

We will ,twice a week, discuss about the progress of our product and also discuss about the possible deadlines that should be implemented. Other than this we have meeting with the mentor twice a month to share our progress and discuss about the possible solutions to some logical problems and also discuss about the agenda for next meeting.

4.4 Sharing files :

We are using github to share the files and also to have the version control in our product.

5 Project Details and Requirements

5.1 Project Details

We'll place some Beacon devices in a building say, museum, office etc. , which will emit BLE signals within a range.

- There will be a central server, with whom smart devices will be connected as a client
- Whenever a client (any smart device, specifically android or ios based) receives a signal from a Beacon device, it will manipulate the received signal and will identify the unique beacon ID code of that specific beacon and will merge that Beacon id with the signal strength (Received Signal Strength Indicator or RSSI) and will send that information to the server with HTTP protocol.
- The server will receive information in HTTP form and will act accordingly with the help of those information.

5.2 Requirements

- BLE signal emitting sources (Beacons).
- Android/IOS devices acting as receivers (client).
- Central host machine (server).

6 Planning and Work Done

6.1 Estimation And Planning

Here we would be briefly describing our approach to reach our goal.

6.1.1 Initial phase(1st stage)

- Since the project is quite complicated, we have divided it smaller sections to ease out our task.
- Firstly, we have set up the basic environment, which includes a single beacon, a smart phone and a server.
- We store some dummy data in relation to the beaconID of that beacon and make sure that basic stuff (like receiving signal from beacon, forwarding it to server and receiving the required dummy data etc.) is all working up to the mark.

6.1.2 Second phase(2nd stage)

- Now the basic environment is all set up, we moved one step forward.
- We now try to identify the positions of multiple objects kept at some distance apart with respect to the set up beacons and the smart phone.
- This is being done to figure out the problems we could face, like for example identifying the positions precisely, no mixed signals, time efficient scripting and stuff like that.

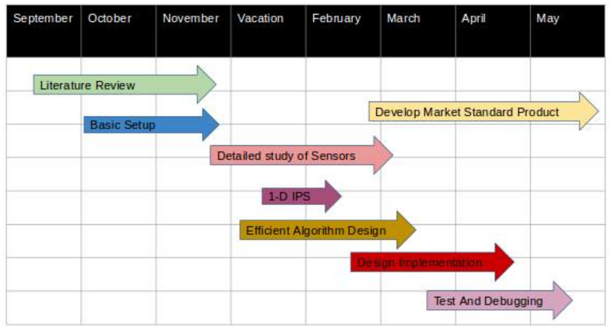

Figure 1: Estimated Time

6.1.3 Third phase(3rd stage)

- We took our project to the entire room(floor). Beacons are set up at different locations in the room, keeping their range in mind.
- Our idea was to implement fingerprinting wherein, we estimated the position of the client with respect to 3 beacons, placed in a room.
- Considering the room made up of small rectangular grids represented as a 2 dimensional array, and given the position of beacons, we estimated the coordinates of client.
- This also helped us to identify number of request our server can handle at a time, and what can be done to avoid such scenarios.

6.1.4 Final phase

- We now extend our project to improve its accuracy. We are now proposing a Deep Learning approach combined with triangulation wherein we try to map the entire structure.
- We consider each of the room grid as a class, and will try to correctly classify the class for a given tuple of RSSI values.
- To calculate the position accurately and more precisely, we can further take the reference of smart device's compass and accelerometer to get the position with minimum error.
- Objective of our approach is to minimize the error within a range of 1-1.5m(2)

6.2 Work Done

We decided to complete the first 2 phases(i.e. Initial and Second Phase) in this semester.
So our work for this semester reduced to setting up the basic environment which includes scanning the beacons effectively and setting up the server.
So we divided the task amongst ourselves in the following manner:
I was responsible for setting up the server and my group mate Abhay was in-charge of scanning the beacons efficiently.

6.2.1 My work

I was responsible for sending the BLE beacon's advertisement data to the server and store that data in database.

- Sending advertisement data from receiver to the server- Using the NSURL-Request and NSURLSession I am sending a http request to a particular ipaddress and port.

- Create a server in local address in a particular port- I have made a server program in NodeJS, which is creating a server in local address in a particular port address and listening that port. Whenever it receives a HTTP url session request, it get the url and store data from the url

- Connect the server with Redis database- For storing data in a server, we are using redis database which is a non-relational database to run the product fast because at a time server may need to store data 10 times per second to get the proper position. So non-relational database can store data faster than relational database.

6.2.2 Experiments

After I successfully complete the coding part, which includes sending data from receiver to server, and server stores that data to database, I have done some experiments with the received RSSI values. Here are my findings

6.2.3 Experiment- Indoor vs Outdoor

We tried to get RSSI values from different distances. We used 1 receiver and three different Beacons (created in a smart phone) and then we tried to plot a graph of RSSI values vs Distance for each receiver. The results are shown below in Figure 2.

6.2.4 Conclusion and Problems

The following points describe the concluded points after the successful completion of the experiment:

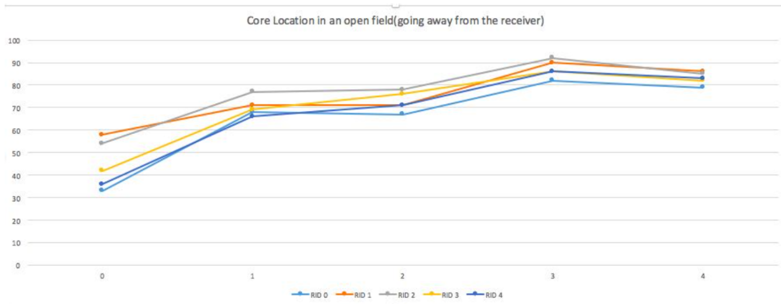

Figure 2: RSSI(dB) vs Distance(meter) Graph In An Open Place (There Were No Obstacles Between Receivers and The Beacon

- The RSSI values fluctuate a lot even when the Beacon is kept very close to the receiver.
- Initially, we used the distance equation to find out the distance of a Beacon to a receiver which needs a calibrated value as well. The calibrated value can be defined as the RSSI value at a reference distance of 1m. So first we started to see the possible RSSI values in 1 meter distance.
- The calibrated values of 2 or more devices were different.
- If the locations of both the receivers are exchanged, then the calibrated values change.
- If some object is placed between an existing Beacon and receiver, the RSSI value received is lower.
- The above point states that on a circle of radius 1m across a Beacon, the RSSI values are different.
- When the orientation of the Beacon is changed, the RSSI values received at the same distance is different.
- The orientation of the beacon plays an important part as well. It is observed that the beacon emits BLE signals of different strengths if it is indented in a different way.
- The fluctuations in the signals increase if the distance is increased.At lower distances,the fluctuations are comparatively lesser than that at higher distances.

6.2.5 Possible Solutions

- Make a region of approx RSSI values by experimenting the value of RSSI for distance with the interval of particular unit distances. If it shows a

RSSI within that region, then the server will tell us our experimental distance of that region.
Pros:
We will have a region of RSSI values, so the small amount fluctuation of values will not affect that much to return a distance of that Beacon
Cons:
We can't have the exact distance as we shall take an unit distance of .5 meter or 1 meter for experiment to take the possible region of RSSI values for that unit distance.

- **Data sampling Outlier removal:**
For every value of the distance, we use the last ten measurements to which we apply filtering techniques. Where we can remove the spikes which happen due to the noise. We remove the outliers with the help of Chebyshev Outlier Detection based on Chebyshev's theorem
Pros:
We can get rid of the spikes due to noise

- **Kalman filter:**
To remove the noise we can use Kalman filter where we can filter and remove the noise.
Pros:

  - Remove the noise more accurately and get a proximate rssi value which would be very similar to the actual transmitted rssi value.

  Cons:

  - If we get a constant rssi value data then to apply the Kalman filter we need to worry about in our constant system is the estimate of the noise levels which are represented by R and Q. 'R' models the process noise and describes how noisy our system internally is. Or, in other words, how much noise can we expect from the system itself? Q resembles the measurement noise; how much noise is caused by our measurements? So we need to make estimate of R and Q based on measurement or domain knowledge.
  - We can apply predict growth in the filter, but then we have to focus on 'A' which is the transition variable that describes how a state transforms from a previous state to the current.

6.2.6 1D - Localization

Inferring from the Loss Exponent Equation, we computed the distance from the beacons using the following formula
Further,we placed 2 ibeacons at 2m distances apart and then mapped the distance between the transmitter and the receiver beacons. An expression for S

(received signal) as a function of distance d. (Friis equation) .If you can measure the direction from two receivers of a known location, you can calculate the position of the transmitter by triangulation. Search for "radio direction finding We divided the distance into 20 equal parts, where one part was equivalent to 0.1m. The above data was stored as a 1D Boolean array placing the beacons at index 1 and 20. The distance between the receiver and beacons is calculated and appropriate index was set to 1.
Calibration While calculating the distance, Since RSSI Value fluctuates a lot, constants were calibrated at different scenarios. We performed our experiment at different venues by calculating different values of constants. An average value was used as of now, but using venue specific beacons could be more useful and can provide improved accuracy which is discussed later.

6.2.7 2D - Localization

Using the triangulation method thoroughly explained above, we estimated the position of the client with respect to 3 beacons, placed in a room. Considering the room made up of small rectangular grids ,represented as a 2 dimensional array, and given the position of beacons, we estimated the coordinates of client. Since RSSI value fluctuates a lot, we sampled it on a time interval of 1s(10 advertisements per second), taking average of10 values. Improving the accuracy of by combining it with machine learning is thoroughly explained in later parts

6.2.8 Drawbacks and future outcomes

One of the major drawback that we deal while working with beacons are that it works only on foreground.One cannot do ranging and distances when the app is in background, which makes it very difficult to determine the location. We can overcome this by putting multiple beacons and by reducing the noise by adjusting the antennae of every beacon. As we know, the Bluetooth signal is just a 2.4 GHz radio wave. In such frequencies, it might be susceptible to various factors like absorption and as such is susceptible to factors like absorption, diffraction, interference and multipath propagation. Therefore, proximity readings might sometimes fluctuate heavily.
There is, however, a handful of methods to improve signal performance. One can test different settings for advertising interval and broadcasting power, change the placement of beacons and make sure to avoid any sources of interference and signal blockers

6.2.9 Deep-Learning for Indoor Localization

In offline phase we generated Feature-based fingerprints, which significantly differs from more popular methods such as clustering. Weights are generated after training the model and used by feature based fingerprints to identify different locations, which effectively describe the patterns(characteristics) of RSSI values measured at different locations.

Feature-based fingerprints server stores all weights for each training locations. In online phase, the client (Smart phone) estimates its position based on data fusion. To get the estimated location, it normalizes the RSSI values using weights from different positions. In our project we used two deep learning model for two different tasks.

Estimating Constants

To determine the values of constants accurately, we trained a model

- We are basically trying to map a given venue to one of the trained venues, the product is tested upon.
- In the training period we have done our experiment at 10 different venues, mostly differing in number of objects it contains.
- For each experiment, we collected the RSSI values from two beacons placed at a distance of one meter from the receiver. These values would serve as data set to the network and corresponding constants were our classes. Thus particular sets of RSSI values are observed for that class
- So this model will find out the best values of constants from the trained data set for a venue to perform the experiment.
- Training phase was in offline mode.

Estimating Position

To increase the accuracy we fused this model with fingerprinting

- Considering a room or floor as a rectangular grid, we devided the grid into smaller grids of an unit sizes.
- We placed 4 beacons at each wall primarily at its center.
- Now in the training(offline) phase, we measured the RSSI value at each of the smaller grids. Here RSSI values combined with combined with venue specific constants served as the data to our network and (x,y) value was our ground truth.
- Intuitively, our deep neural network learns a "fingerprint" or specific pattern for every set of RSSI values and corresponding position(x,y coordinates) and makes predictions based on which "fingerprint" the new data point matches best.
- We fused the result with the one calculated using triangulation to increase our confidence of our result.

Tuning
Tuning of parameters would be done completely in offline phase, size of model would be chosen based on experimental results. Moreover, to have a further control over the trade-off between computation speed and accuracy, number of layers could be used. When we keep on increasing the number of layers training error decreases but the computation time increases significantly. To make sure model does not over-fit the training data, regularization techniques such as dropouts would be used.

6.2.10 DoNotGetLost: Indoor Location Application

This application is to navigate in a large indoor building. For demonstration purposes, we would be using lounge in C1 mess.
For our demonstration, we used six beacons for a large room, although only 3 is sufficient to get the position, but to increase the accuracy we have used 6 beacons to get more accurate result.
Mapping The Room
We built a 'configuration' app for setting up the structure of the room. This app makes sure that the tested venue is configured and calibrated properly.
Details of configuration application are as follows:
In the configuration stage app defines shape and size, which includes setting up origin, providing the coordinates of placed beacons and other small things.
Building DONOTGETLOST Application
After building the configuration app, we built a main application to estimate the position.
We have connected our application to the server wherein all the data would get saved. Locations would be fetched from the server afterwards.
After the configuration part server has all the information of origins and coordinates of all the beacons. In the server it uses the trained model to estimate the constant to be used in Log-distance model. So we have 3 distance from 3 beacons, so now by the triangulation method we can easily get the exact coordinate of the smartphone from those 3 beacons.
FETCHING COORDINATES FROM THE SERVER
After calculating the coordinates using the estimated constants and RSSI values from the beacons, it's time fetch them back to the IOS device to show real time position.

6.2.11 Smart Guide

There are many applications we can make using this technology, here is one more application we built, a Smart Guide application, which is a replacement of the traditional guides in the museums with our app.
This app will navigate tourists in a large indoor place like museum and whenever that person goes near an attraction where beacons are installed, all the data

of that attraction attached with that beacon would be played on that person's smart-phone
With the help of this app people can roam around in a museum without any guiding information, they can also have all the details related to all the attractions in the museum easily.
We created database on the server which includes beacons and the attached information with that particular beacon id. This app will run in the phone and Whenever someone come in the range of a beacon, it will fetch that beacon's id and then it will fetch the data related to that beacon's id from the server

6.2.12 Attendance Monitoring System

We also built an Attendance Monitoring System which wold come very handy in universities like IIT Mandi in upcoming years. Automatic attendance marking system can be used in schools and universities in many way. It will save time and money by eliminating the manual attendance system with the automated attendance system by which teachers can easily monitor students' time in the classroom.

Advantages:

- Reduce paperwork, money and time with phone and cloud-based attendance system.
- Eliminate any duplicate entries
- Improve visibility to manage and track students' attendance.
- Increased security and confidentiality with role-based permissions to users.

Every Beacon has it's range, So we defined a small range across the door. Whenever someone crosses the door with smart-phone, it will mark its id and send the details to the server and store it.
By using these details we can also monitor the time spent by a person in a place. From that we can calculate the Heat Map of a place, we can see the utilization of a place or room in a building. Other use cases of building such application is that by using user specific details we can also monitor the time spent by a person in a place. A heatMap of the place can be made which would provide us valuable information regarding the utilization of a place or room in a building.

6.3 Future Work

We tried to increase the accuracy using a quite old algorithm on it's core. Working on newer algorithms combining it with machine learning the way we did, might be able to achieve greater accuracy. Bluetooth Low Energy would take on the context aware market in the near future. Localization applications can help us to take one leap forward towards building the smart cities. In Administration and Governance field, customer engagement can be increased to businesses by providing extra information on location and actions of customers enabling immediate feedback. Areas such as tourism, recreation and culture are most benefited ones from BLE. Marketing campaigns, attracting tourists by providing context specific offers and tourist cards are some of the projects to work on.

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