Beacon deployment guide: A study on bluetooth low energy beacon infrastructure setup for indoor way-finding

BEACON DEPLOYMENT GUIDE: A STUDY ON BLUETOOTH LOW ENERGY BEACON INFRASTRUCTURE SETUP FOR INDOOR WAY-FINDING

A Thesis by

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The following faculty members have examined the final copy of this thesis for form and content, and recommend that it be accepted in partial fulfillment of the requirement for the degree of Master of Science with a major in Computer Networking.

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I dedicate this thesis to my parents.

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ABSTRACT

With the recent technological advancement in providing exploratory and navigational aids to individuals, especially people with visual impairments, in an indoor area, usage of different kind of markers at Point-of-Interest (POI) has turned out to be one of the efficient ways to cater these needs. Most commonly, these markers are usually Low Energy Bluetooth beacons. These are deployed and configured to provide exploratory aid and navigation instructions. Generally, these beacon nodes are translated into an indoor space graph. Picking out the beacon location strategically and translating this to form a topological graph is a onetime process for any indoor space. However, these tasks could get more tedious and respective for a complex floor plans and can lead to errors. This work presents a study on different stages of beacon infrastructure deployment and a web tool developed to perform these activities. The tool generates the information and posts it to the database that can be downloaded by the smart phone for way finding purpose. The web tool allows building admin to mark beacon on a floor plan and create a graph using these points. Evaluation highlights the difference in time and accuracy for multiple floor plans tested by several users. These evaluation metrics are compared with IBeaconMap [1], a similar tool based on MAT-LAB which automatically determines POI on a floor plan using computer vision and machine learning techniques. The work helps in classifying the beacon deployment process into categories that could be simplified or automated in future.

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CHAPTER 1
INTRODUCTION

Indoor way-finding can be explained as a process of knowing where a person's current location in a building or an indoor space is, looking up for the desired destination, and finding a suitable route or path to get there from their present location. For outdoor environments, usage of global positioning systems (GPS) and its mapping technologies provide accurate, fast and easy means of way-finding. All these technologies use a prior infrastructure development to provide access to the Point-of-Interet (PoI) and route data gathered. For indoor space way-finding, GPS and associated advances for outdoor environments are not very accurate. Hence, reading boards and following signs remain the fastest, easiest and most reliable options. However, this way of that indoor way-finding are not applicable to a part of our society who are blind and visually impaired (BVI) and this has remained a challenge for a long period of time. Indoor environments can be geographically large and intimidating such as grocery stores, airports sports stadiums, large office buildings, and hotels. A solution to the indoor way-finding problem for the BVI also has broad applications for the sighted population. In unfamiliar, large indoor spaces, it is common for even typically sighted people to be disoriented and have trouble finding their way around. This could be due to the lack of well-marked signs and maps, or not being familiar with the conventions or language used on this signage, or just the fact that the layout of the space is disorienting.

In the past, some of the accurate and usable indoor way-finding systems, [2], [3], [4], available to people with visual impairments, used to rely on the use of radio frequency identification (RFID) tag technology. This solution however is not very flexible when it comes to changing embedded information on tags; furthermore, the tag reader technology is expensive and can be difficult to integrate into current mobile systems. Other mechanisms that provide audible directions such as TalkingSigns [5] still need each user to possess special audio frequency devices capable of acting as receivers. In general, most approaches to solve this challenge require special hardware to be

carried by the user. Such limitations have created barriers for widespread use and adoption for indoor way-finding. Recent work has developed a system of way-finding for the BVI using low-cost, stamp-size Bluetooth Low Energy (BLE) "beacon" devices embedded in the environment [6], [7], [8] that interact with smart phones carried by users. Such beacon based navigation systems have achieved promising preliminary results indicating that they may be a viable solution for indoor way-finding for the BVI if some of the underlying challenges to the deployment of such systems can be solved.

One of the major challenges to develop an accurate BLE beacon-based indoor way-finding is finding out the right places to places the beacons on the floor. The other major challenge is translating the indoor space into an accurate graphical representation that can be stored in the database. Determining accurate PoI requires some expertise and can impact the accuracy of the indoor navigation system. These beacon location can be used as nodes and connect them to each other in such a way that represents the possible walk-able space from one node to the other and this information can be used in subsequent navigation computations - a process that we refer to as beacon infrastructure setup in the rest of the document. Walking around the floor or looking at the floor plan to find out the markers location and calculating the distance and orientation path between each beacon location is some time tedious and time-consuming and labor-intensive, especially for large indoor spaces. Such an approach requires the manual identification of walking paths on a floor plan, marking of points of interest, determining the distance between any two points of interest, determining the orientation between them for navigation, computing shortest paths between points of interests, and subsequent adjustments to optimize the resulting paths that may require further iterations of the entire process. Other approaches of using robots or crowd sourcing are efficient yet expensive and difficult to execute and maintain. [9], [10]. The process should be run every time upon a new poi addition or removal or any layout changes. On the contrary, a floor plan does change too often, and this is a onetime process per floor plan and might not need a system that requires complex, expensive automation system end-to-end.

This study presents a web-based tool that allow beacon planning which that translates the data

into graph which can be loaded into any database. The tool allows the building admin to upload a floor plan, draw beacon markers on the floor plan and connect the markers using possible path. It also allows to load information into each of these markers and add the distance and orientation details of each path connecting each marker. All of these are loaded into a table in the database. To calculate the need and scope of an automated system, we evaluate this tool by tracking the time taken to complete different beacon planning activities. The evaluation of this tool shows how a time and accuracy changes from easy to a fairly complex floor plan. Since, the tool gathers time and accuracy for each of deployment activities, therefore it is very helpful to know if more research needs to done to automate what part of the process.

Figure 1.1 shows the overall working of beacon based way-finding system. The user's device downloads the route map from the database and computes the required beacon information and navigational route between the required source and destination. The beacon setup needs to be done before hand and working graph of an indoor space should be stored as part of the deployment activity.

The tool is deployed to be used publically and can be accessed by clicking on this link: `https://beacondeploymentguide.herokuapp.com`.

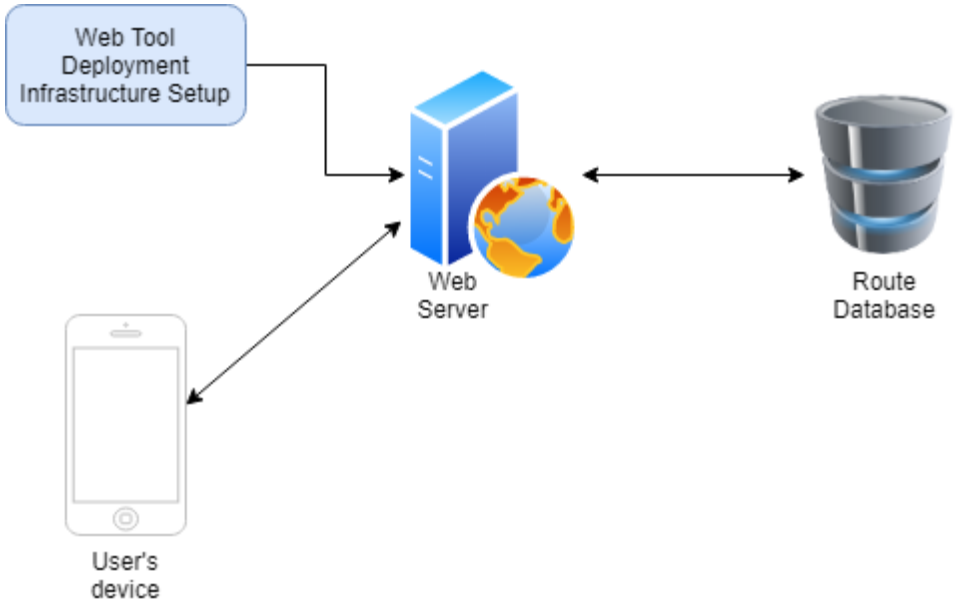

Figure 1.1: Building blocks of a typical indoor way-finding system.

CHAPTER 2

LITERATURE SURVEY

This chapter describes some of the related work in the area of indoor way-finding techniques and the deployment requirements to map an indoor space into a suitable graph that can be translated by the system to provide location information as well as turn by turn navigation.

One of the major indoor way-finding requirements for BVID is to provide the right exploratory or navigational instructions while the user is walking through the indoor space. To achieve this, it is not required to always know the user's location at all times; rather it is more important to identify strategic areas within an indoor space that a user should be localized at accurately with minimum localization error. The direction of using existing infrastructure in indoor spaces recently has largely revolved around using Wi-Fi access points that are already present. Under various assumptions, prior work has shown accuracies within a few meters (for e.g. [11], [12], [13], [14], [15], [16], [17]). Although this method of indoor localization can help build way-finding techniques without any additional infrastructure costs, and allows users to use mobile devices they carry, they have many limitations in terms of access points density requirements, dead spots and best accuracy possible. Different types of wireless devices that can be added in an indoor infrastructure has been explored for several years, primarily to boost the existing localization accuracy, compared to Wi-Fi based systems. Such work has included the use of technologies such as RFID (e.g. [18], Ultra Wideband (UWB) (e.g. [19]), Ultrasound (e.g. [20]]), Infrared (e.g. [21]), and visible light (e.g. [22]). Many of these technologies, some specific to indoor way-finding for BVI such as [5], [23], are not effective for indoor way-finding and have rarely been used because of the requirement of carrying additional hardware on the user, or more expensive or power-inefficient reference nodes in the environment. There have also been many attempts to use computer vision techniques to read and understand signs (as pointed out in [24]) to assist with way-finding for the blind and visually impaired; these tend to have high inaccuracies in the information read out when

a user is mobile and text is not directly facing the user. Bluetooth-based indoor localization is not new (e.g. [25]), but it only gained traction after the revision in 2010 and the introduction of BLE.

Other work with the Apple platform showed accuracy as small as 0.53 m [26] whereas others focused more on the techniques that can be used to improve localization accuracies [27]. There have been three recent works using BLE beacons for way-finding for the BVI, GuideBeacon [6], NavCog [7] and StaNavi [8]. All of them report significant improvement in the ability of the BVI to navigate unfamiliar indoor spaces independently using the developed systems. Other efforts include the Wayfindr project (`https://www.wayfindr.net`) which is an effort to develop an open standard for navigation for the visually impaired in outdoor and indoor spaces, including the use of BLE beacons. Other systems for indoor navigation for the BVI using beacons such as BlindSquare Indoor Navigation (`http://blindsquare.com/indoor`) and Indoor Proximity Marketing and Tracking (`https://indoor.rs`) are more for providing location updates as a user walks through and are not turn-by-turn navigation systems such as GuideBeacon, NavCog and StaNavi.

Apart from various BLE beacon-based navigation systems being developed, efforts to design a fast, and largely automated method for representing indoor spaces as topological structures for accurate and timely beacon-based navigation have been going on for a while. Work related to creating representations of indoor spaces have been around for a while (e.g.[28], [29], [30], [31]). These can mainly be differentiated based on the approach used in collecting the required information and in the techniques employed to create the desired representations. An automated tool, IBeaconMap differs from this class of work by automating end-to-end process for beacon-based way-finding that include beacon location markings, indoor paths connecting these locations, a weighted connectivity graph as topological structure representation, and directional orientations for paths but this kind of the tool requires complex mathematical computation and complex image processing. Other than this such kind of automatic image processing works only the floor plans are consistent in terms of PoI representation. If different floor plans have non-consistent ways of representing PoIs like door, stairs, such tools do not work efficiently. Another drawback of such a tool is that

for floor plans with a large open space, it fails to determine the possible beacon location as there is no way to understand what could be the potential PoI in such large open space indoor area. Other additional approaches for beacon deployment planning involve robotic mapping and crowd-sourcing [10], [32], [33], [9] to perform all the activities. This kind of system fails in the aspect of maintainability and scalability. Robotic mapping approaches are expensive to time consuming to implement. While crowd sourced approaches work the best in terms of one time process and may be inexpensive but fails in terms of consistency. The recent work on using crowd-sourcing to deploy beacons in [34] assumes that beacon locations are already known. The only way to know this to physically visit the floor or use the floor plan to analyse all PoIs before deployment.

CHAPTER 3

BEACON DEPLOYMENT CHALLENGES

Beacon placement needs to balance the cost of installation and the effectiveness of right information at the right time. Although beacon cost is not very expensive the costs can go very high if it is placed densely. These beacons also need timely maintenance of replacing batteries. Thus, each beacon should be placed judiciously based on its utility to the overall goal. More beacons can possibly improve the accuracy and information in a timely manner as an when the user reaches the right spot (if deployed carefully), but this might lead to a bigger challenge of handling the multiple beacons received signal at the same spot. This makes it more difficult to decide which beacon proximity is the closest due to the unpredictability of the wireless signal [27].

The POI selection process includes the calculation of the right trade off between weight-age of accessibility information vs the beacon cost and signal interference. One fixed way of accessing this to make sure any entrance of the floor or room can be considered a suitable place for beacon placement. What could be a better place to the space layout details ahead of time better than the entry door? Other specific location can be the interest points in an indoor space whose information can vary during the different intervals of the day.

3.1 Beacon Placement

3.1.1 Marking POI

The results using beacons for knowing proximity information, is straight forward. But if you wish to create accurate indoor positioning with beacons, things get a bit more complex. There are a number of things both from the software development side, and the beacon placement aspect that you need to take into account. With careful preparations it is possible to reach 1-2 meters positioning accuracy with Bluetooth beacon.

This preparation requires accurate placement of the beacon to capture utmost poi location consisting the floor plan. Determining the right spot and density of beacon markers play a pivotal role in the overall indoor exploration efficiency. Also, for each installation it is practically impossible to go around the location and physically inspect every possible point in an indoor space to find out the beacon location. It is often easy to do this on a floor plan and cross check it during installation.

3.1.2 Mount Height: Beacon height from floor

Bluetooth BLE beacon's signal can vary hugely based on different factors placed in the surrounding. Obstacles made of iron and other heavy material can cause some disturbance. But the most important factor is the mount height of the beacon which can be a game changer. When aiming for great location accuracy results, it's the best to place the beacons on the walls at a certain height based on different factors. Some of the key factors are play a significant role determining the mount height are crowd and object density and proximity coverage. When the signal is coming from above, it's easier for your smart device to receive it. It is always recommended to place them somewhere visible. But with different floor plan layout, this can vary and can have a significant impact on the system.

3.1.3 Beacon advertisement information

A Bluetooth beacon has no location intelligence built into it. Like their name gives away – they are like lighthouse beacons transmitting Bluetooth signal around them, expecting nearby smart devices to pick it up and understand its meaning. Depending on iBeacon, Eddy stone protocol or some other protocol, beacons will be either transmitting their UUID, major and minor values or their name space and instance IDs. In order to turn these values into real-world information, each of these beacons physical coordinates should be translated inside the app, or in an external database.

The amount of information varies from point to point. For example, a restroom door can be mentioned as a bare "restroom door" at first but the non-sighted users might want to know the

layout of the restroom for their ease of use. This are called secondary information and there can be multiple layers of secondary information based on what the user needs and should be delivered accurately based on user's need. Such a feature demands a complex database that should be flexible for any information update. Without a simple and easy GUI tool this can become a very tedious task while dealing with hundreds of PoIs and each POI with several layers of information.

3.1.4 Tuning of Bluetooth Power and Antenna Direction

As discussed above the beacons placement is critical in terms of the accuracy of the system. The more accurate system might make use of densely place beacons across the indoor space. This brings in another challenge of Bluetooth signal interference. A particular spot, there a user's device might receive several strong signals from different BLE beacons making it very confusing for the device to translate it to the actual information. This can lead to delivery of wrong information. Similarly, the beacon manufacturers provide the flexibility to change the antenna direction from omni-directional to unidirectional and vice versa in order to fine tune the system. This can also be factor that can impact the performance of the system.

One way to handle this is to tune the device's transmission power, threshold and antenna direction in such that only at the right zone or the required area on the floor plan the beacon gets detected by the phone. Knowing the exact transmission power that lead to a stable and minimum interference system is very challenging. This process is often called as configuration tuning. Tuning can be extremely time consuming if this is done by trial and error every time.

3.2 Indoor Space Graph Generation

To create a navigation system to direct user from point A to point B in an indoor space, there needs to be a graph generated using the beacon markers as the nodes of the graph and path between nodes as edges. Each node should carry a weight to determine how suitable the path is compared to other paths from the same node. Distance between two nodes can be considered as weight for simplicity. On the final graph data of the floor plan, Dijkstra's algorithm can be applied to find out the shortest

distance to direct user to a destination.

Although, it is easy to look at the floor plan and visualize how the graph could look like, it is extremely difficult to translate it to useful database information. Finding out connecting edge's distance and right compass orientation relationship between them, and posting it to database can take up to weeks for a moderately complex floor plan. If this needs to be done for several floor plan, this does not scale well as it might make more than several weeks. In order to speed up this process, there needs to some mechanism to draw the graph on floor plan and that generate the required data post it to database automatically.

CHAPTER 4

SYSTEM OVERVIEW AND DESIGN

This section provides some details about the beacon deployment process adapted in the tool to generate the relevant weighted space graph representation of the floor. The beacon deployment process ranges from uploading a floor plan to draw the graph connecting all beacon markers. Each steps consists of several aspect of information collection. The sequence of the activities is shown in figure 4.1

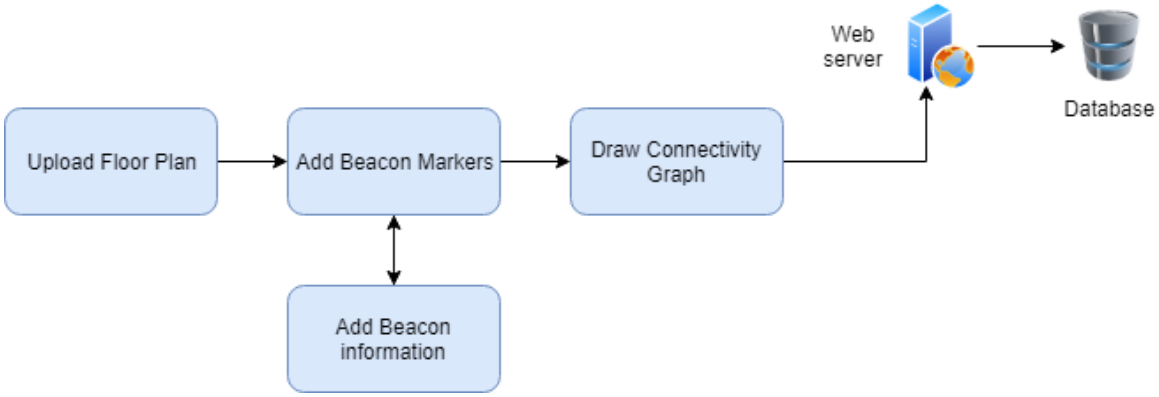

Figure 4.1: Sequence of activities that can be performed on the web-tool.

4.1 Beacon Placement

When you have room large enough and the dimensions of it, something you may want to think of is the indoor-outdoor transition. If you are placing beacons to e.g. a shop, you might want to add one of them right next to the entrance. When a customer with a smart device and your application installed on it enters or exits your shop, the event will be triggered. Besides to this scenario, there are multiple other circumstances where you may want to apply this information. If you are aiming for accurate location in a building with multiple floors, it's recommended to add beacons right after entering/exiting staircase, escalator or a lift. Your smart device doesn't understand the differences

between the floors itself and that's why it's important to place a beacon right after the floor change happens. This is also important for potential way-finding purposes.

A floor plan is a drawing to represent indoor space's details such as room, doors, intersections, stairs, elevators, exit, etc. A complex floor plan could show interior walls and hallways, restrooms, windows and doors, interior amenities such as fireplaces, saunas and whirlpools, rest areas, service counters and many other regions within buildings. For a way-finding system to work, any such region which is relevant to user should be highlighted. These points are represented using specific symbols on a floor plan and are standardized between various architectural drawings. The first step to use the tool is to have a basic understanding of these POI symbols on a floor plan. The tool allows you to upload a floor plan in an image file format as a first step and view the floor plan in its original scale. It provides an option to analyze a POI by zooming in the image. Once the image is uploaded and all the POI symbols are analyzed well, the user can then start marking the point of interest.

When the user clicks on the floor plan, a beacon maker gets generated at the clicked pixel point. On the background, we capture the top and left pixel of the marker point with respect to the image absolute pixel size. The marker is generated with a 14 digit default UUID code, transmission power, antenna direction and threshold. A threshold is the RSSI value at which the beacon is detected by the phone. To delete a marker, the user has to click on a marker and then press the delete button that appears on the side drawer. At the end of this stage, all the pixel locations of the markers are obtained along with the information about each POI . Figure 4.2 shows the markers placed on a floor plan.

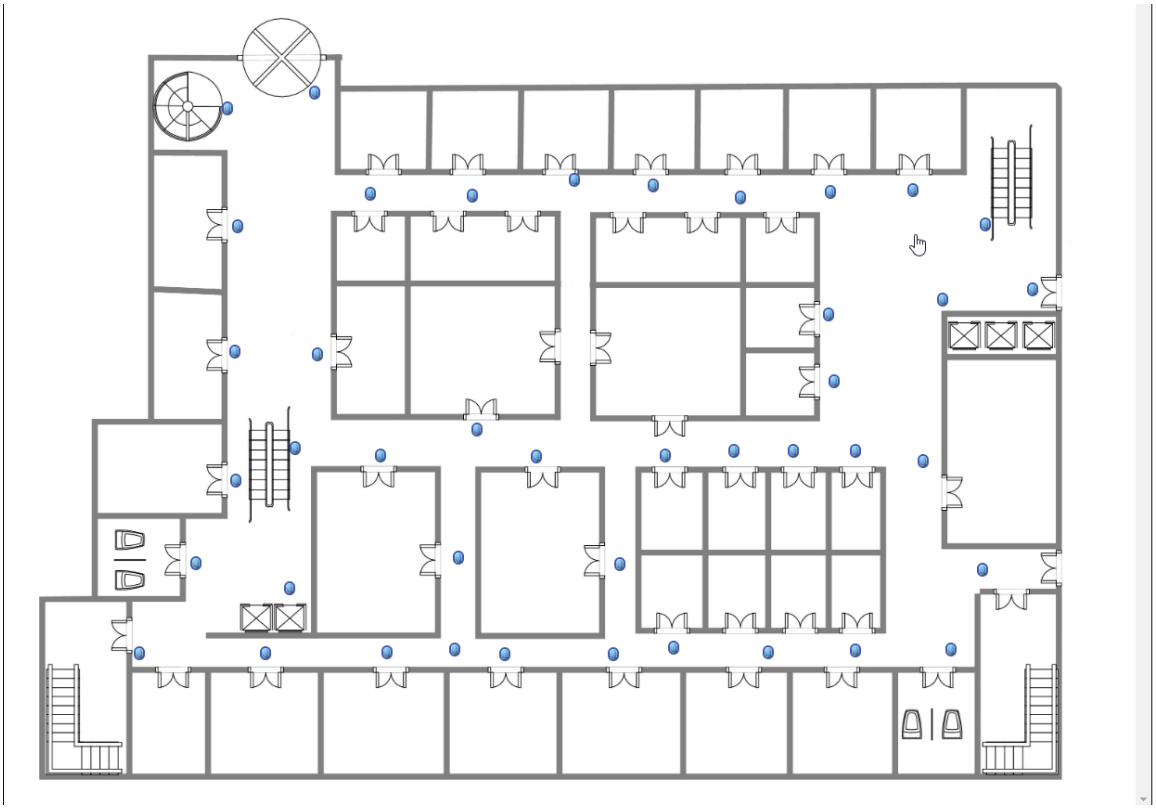

Figure 4.2: A floor plan marked with beacons.

4.2 Beacon Information Layer

There are several types of information which are significant for different kind of disabilities. Particularly in the case of BVID, space orientation, layout details, location of interest areas are extremely useful. Similarly, a beacon can be placed strategically to deliver information for several PoIs based on phone's compass orientation.

Once the beacons are placed on the floor plan, the tool allows users to click on a beacon marker and add all the required information along each direction of the marker as shown on the figure 4.3.

Each direction can hold up to several layers of information. The default information would be the POI name or basic one-liner about POI. If there is any other information that is essential for people with disabilities and can make the way-finding or exploration of the place more meaningful, then such information can be broken down into several layers in terms of its message value. Message value is a term defined to sort the information in terms of its usefulness for people with

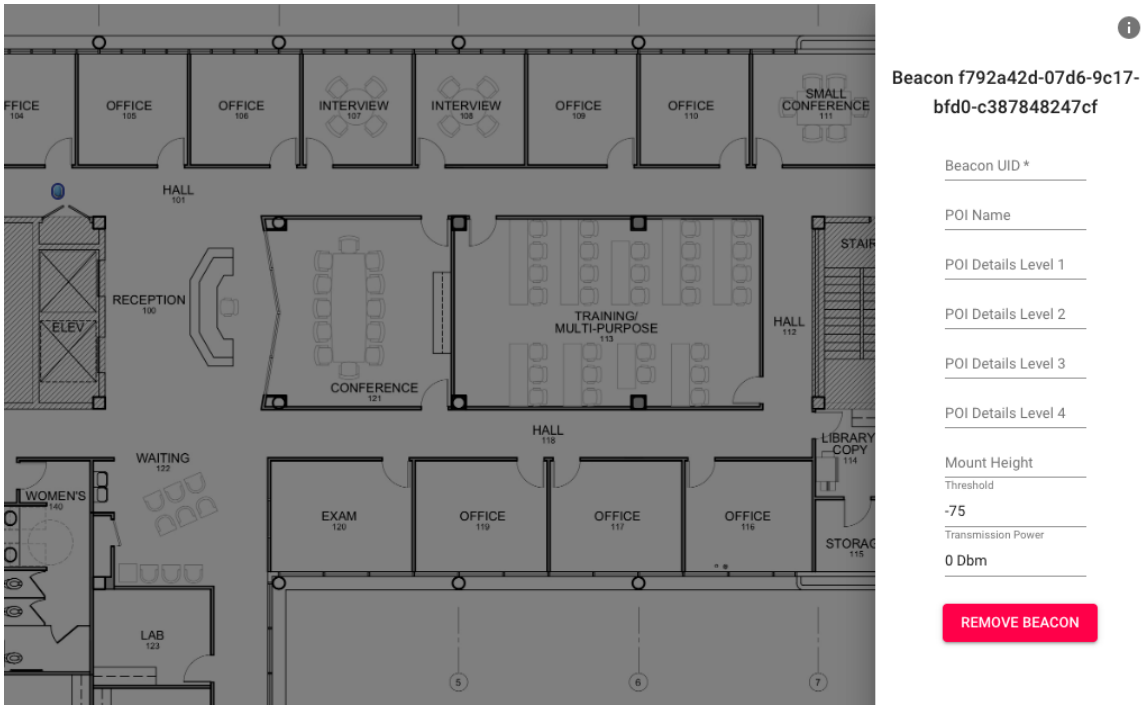

Figure 4.3: Dialog box to add beacon related information.

disabilities. The system can be integrated with a new module called Information Classification Engine (ICE) that is designed to break down the details of POI into several layers of information and assign priority based on what information should be first delivered to the user in order to provide assistance. Lower the priority, less important the information is and can be provided only if user really wants to learn more ICE is designed to implement supervised machine learning classification to bucket the sentences based on the keywords like room area, directional details etc. This is capable of learning and making the changes automatically over time.

4.3 Beacon Configuration Tuning

Tuning factor is directly related to distance between two beacons and objects in between it. To handle the beacon tuning, the tool uses a specific bucket or classification algorithm developed based on past trail and run data. Data from several deployments in different buildings was collected to find out relationship between RSSI interference, mount height, beacon transmission power and antenna direction apart from basic relationship between RSSI value captured at a certain distance

for a certain transmission power. For simplicity purpose, distance between two beacon markers are considered in terms of pixels. These pixel values are translated roughly into standard distance unit to perform algorithm condition matching.

The beacon manufacturers usually have RSSI vs Transmission power table listed specific to their device. Table 4.1 shows the average RSSI measured at a particular distance over a period of time. This is an approximated average value and can no way be constant at all times due to the nature of wireless signal. Leveraging this information, the tool implements a simple classification algorithm based inter-beacon distance and presence of large obstructing objects on either side of beacon. The classification condition used in the algorithm is shown in algorithm 1 below. This value is determined automatically when the beacon tuning condition is selected as auto. Otherwise, user is free to manually change this value based on the floor plan and user expertise level.

On click on any beacon, a side drawer pops up where these configuration values are shown for each. Configuration values are set to default values specified by the beacon manufacturers. Threshold is set to -75 by default. These can be tuned by setting it to auto to use the value generated by the algorithm or changing the value manually shown in the figure 4.3.

TABLE 4.1

Average RSSI measurements at predefined distances.

Distance	Average RSSI
1m	-70dBm
2m	-75dBm
3m	-78dBm
4m	-82dBm
5m	-87dBm

Algorithm 1 Calculate $Power_{Transmission}$, $Direction_{Antenna}$ and $Beacon_{Threshold}$

Require: $distance_{NearestBeacon} = dist$
Require: $LargeObstructionPresent_{Beacon} = True\ or\ False$
if $dist \leq 2m$ **then**
  $Power_{Transmission} = -4dBm$
  if $DetectionPoint > 1m$ **then**
    $Beacon_{Threshold} = -75$
  else
    $Beacon_{Threshold} = -73$
  end if
end if
if $dist > 2m\ \ \&\ \ dist \leq 4m$ **then**
  $Power_{Transmission} = -2dBm$
  if $DetectionPoint > 2m$ **then**
    $Beacon_{Threshold} = -77$
  else
    $Beacon_{Threshold} = -74$
  end if
else
  $Power_{Transmission} = -0dBm$
  if $DetectionPoint > 4m$ **then**
    $Beacon_{Threshold} = -77$
  else
    $Beacon_{Threshold} = -75$
  end if
end if
if $LargeObstructionPresent_{Beacon} = True$ **then**
  $Direction_{Antenna} = Directional$
else
  $Direction_{Antenna} = OmniDirectional$
end if

4.4 Graph Data Generation

BLE beacons are typically placed strategically in the indoor space and include both PoIs and other points that may be useful to improve the navigation experience. Thus, in a connectivity graph of the indoor space, PoIs will only be a subset of all beacons. All beacons could serve as vertices of this graph, and paths between them as edges. To compute useful end-to-end routes, the physical distance and difficulty level of a path must be encoded as a weight to the connectivity graph; a

shortest-path algorithm could then return the most favorable path for a user. In addition to characterizing path difficulty as weights, the directional orientation of paths must be stored so that users can be directed to their next point along the route to the destination. The tool allows to perform this by drawing the path between two beacon markers and enter the path attributes, distance between two markers (considered as weight) and compass orientation of the path (left to right or top to bottom). For simplicity purpose, distance between two beacon markers are considered in terms of pixels. These pixel values are translated roughly into standard distance unit using approximate pixels to distance conversion table.

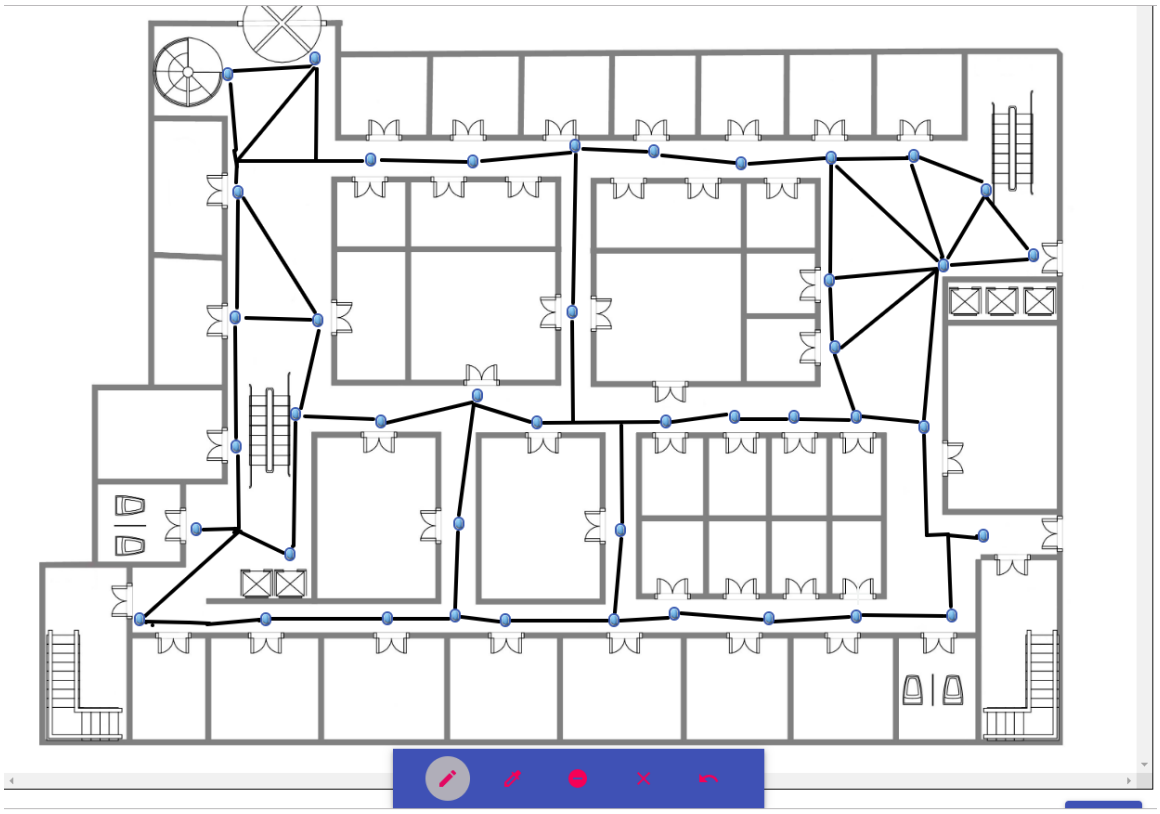

Figure 4.4: Connectivity graph of the beacons on a floor plan.

The system provides several options in the toolbox kit to draw the lines between PoIs such as draw, erase, undo, erase all and select. Draw tool provides a cursor to create a line as graph edges between markers. As soon as you create a line, a pop up appears on the screen which allows the user to add the attributes of the newly created line. Select tool is used to select a line and modify

its attributes. Figure 4.5 shows the toolkit provided to complete the connectivity graphs between all beacons.

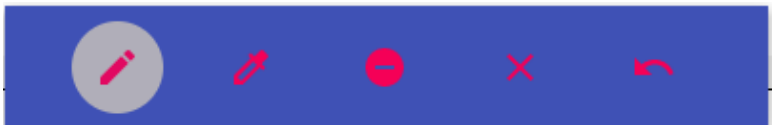

Figure 4.5: Toolkit to draw connectivity graph.

Behind the scene, we capture start and end pixel coordinates in terms of (x,y) of each edges and map its attribute to form a collection of edge objects. This is combined with the beacon marker information to form a complete graph to represent the indoor space.

After completing all these activities, the data can then be pushed into the database. The user can then place the BLE beacons physically on the floor exactly at the spot that was chosen on the tool and the system entire should be up for use.

CHAPTER 5
SYSTEM EVALUATION AND RESULT

The main objective of the system is to ease the deployment setup of beacon based indoor way-finding infrastructure. There are several ways in which we have evaluated this system in order to find out the effectiveness, correctness and usefulness of the system. Each of these metrics are explained in detail below.

5.1 Methodology

To test the tool we forwarded the tool link to 10 users, all with a computer background to know the best time or the lower threshold to complete all the activities. All the users were familiar with the way-finding concept. However, they were not given any information on the activities and scope of the tool. The concept introduced in the tool were new to all the users. We asked each and every user to evaluate the tool using a floor plan. This floor plan was kept in common for all the users. In order to compare the tool in terms of time and accuracy with IBeaconMap, which is described below, we used one of the floor plans to evaluate IBeaconMap.

The scope of the task was limited to adding beacon markers and drawing the connectivity graph to represent the path between these nodes. Adding information about POI and beacon configuration were excluded from the tasks to measure time. However, to evaluate the overall effectiveness and efficiency of the tool, a site deployment was performed and the database was generated using the tool. To test the extreme case, 3 users out of 10 were asked to evaluate the tool with a very complex floor plan. Again, this is also one of the floor plans used to evaluate IBeaconMap. The two floor plans used to evaluate the tool are shown in figure 5.1 and 5.2.

This was done mainly to evaluate to get insights on the need of such a manual tool while working on complex floor plans. Since IBeaconMap automates some of the process described above, but do not generate the final database entries, getting insights on which part of the activity

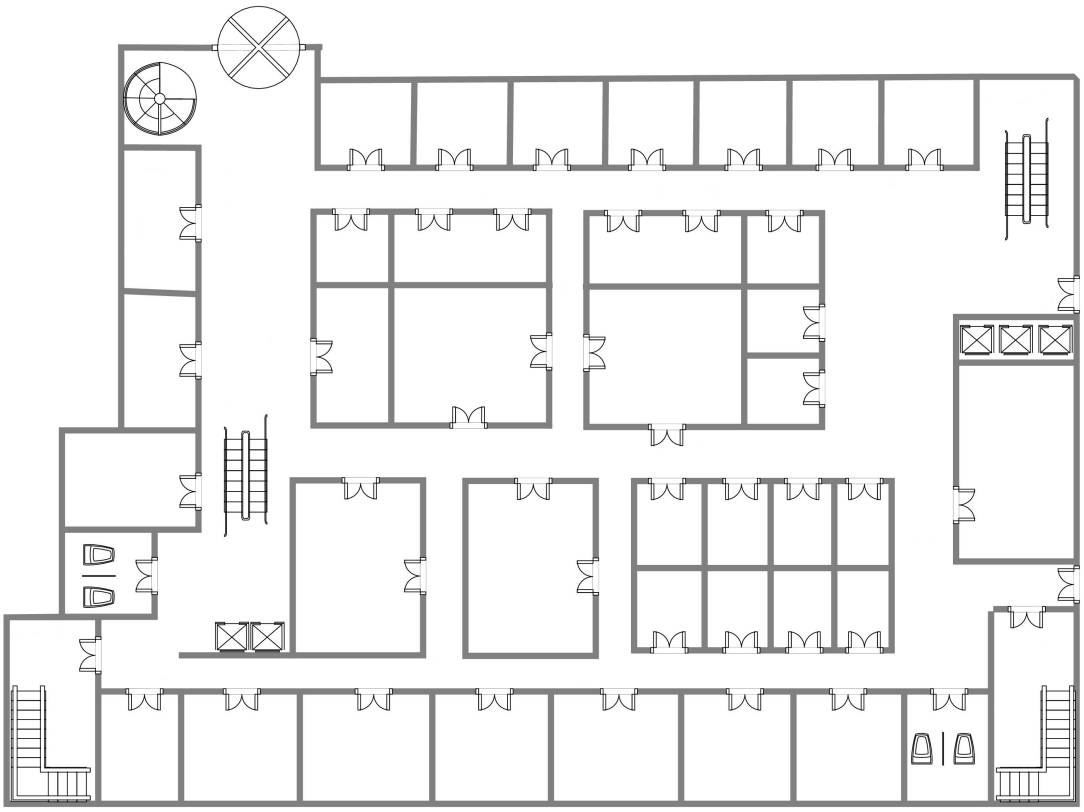

Figure 5.1: Simple floor plan: floor plan of a shopping complex.

is considered redundant when done manually and is time consuming. This defines the scope of the task in the tool that should be done manually by the user and brings in the scope of automation where the task is redundant and time consuming. All the participants were rewarded after their submission. These submissions were recorded as an object stored in a text file and were not posted to any database.

5.1.1 Time taken to complete each activity

There are three sets of tasks defined while evaluating the tool. The flow of the task is defined in the block diagram shown in figure 4.1.

In the first stage, all the users are given a link in the web tool to read and understand the instructions on how to use the tool to mark beacons on floor plan and create a connection between them. To do so, the instructions also train users on how to identify potential POI and how to mark

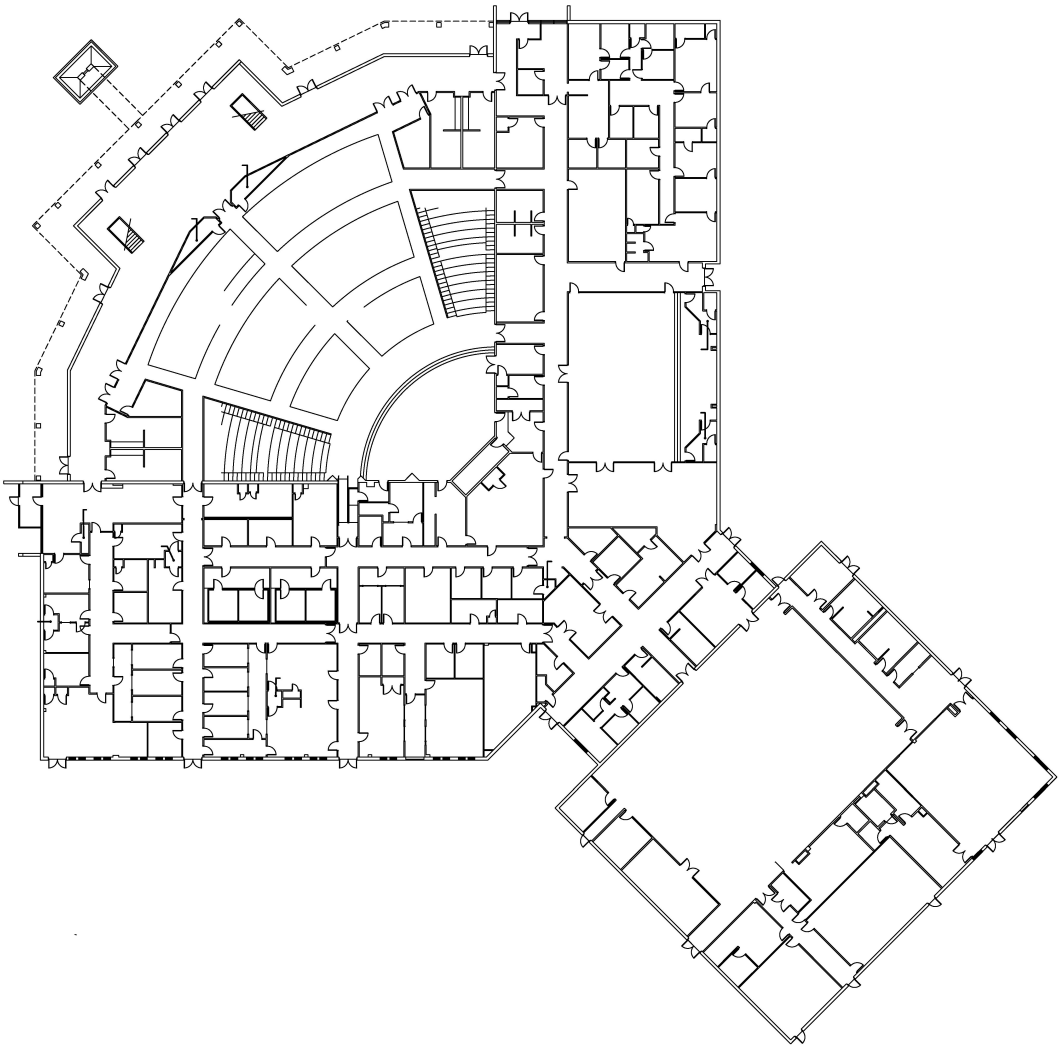

Figure 5.2: Complex floor plan 2: floor plan of a large campus.

them. To draw the connecting edges on the floor plan is not as simple as marking beacons, so the instructions is well described to add sufficient information on each draw tool on the tool kit which is used to draw the graph. The help page designed to provide all the instructions on how to use the tool can be accessed on `https://beacondeploymentguide.herokuapp.com/instructions` and is provided in Appendix A.

Since all the users were new to this tool, we captured the time taken for each of them to go through the instructions and understand it clearly. This was done to know on an average how much

time a new user spends to learn to use this tool.

The next step designed was to upload a floor plan and mark the beacons on the floor plan. Post this the next activity designed was to draw the connecting edges between these markers.

For each of these activities timer value was captured individually to record the task completion time.

5.1.2 Deployment at two sites

One of the early deployments of this way-finding system was done at of the eye institute in Wichita where the first few beacons were tuned (threshold, transmission power, antenna direction and mount height) based on trail and error. Mount height approximation cannot be done until the floor height, object height etc are determined. This field for now can be edited manually and the tool does not carry the logic to generate this automatically. Using this as the learning data, an algorithm was designed to output the same configuration, given the same input conditions like, distance between two beacons, presence of obstacle like wall etc. on any side of beacon. The same algorithm was then used to tune the others beacons placed on the same floor.

The next end to end deployment is now being done at Wichita State University Ulrich Museum the deployment infrastructure is created end to end using this tool. Also the beacons would be tuned based on the auto recommendation by the tool. This is planned to be done by August.

5.1.3 Subjective feedback

Apart from all the metrics, the most important factor used in evaluation was asking users about their comments on what part of the activity is not do-able or time consuming or any other subjective opinion about the tool and the approach can be improved. This is a wide perspective evaluation to know the overall tool usability and effectiveness. Scope of automation can also be partly derived based on users' opinion on what part of the activity cannot be done repeatedly or is more prone to errors if done automatically vs manually. Subjective feedback is quoted as it is to maintain the integrity of the users emotions.

5.2 Result

All the metrics described above are recorded in terms of table and are described as follows.

5.2.1 Time vs Accuracy

Table 5.1 shows the time taken by 10 users to learn the use the tool reading instruction (learning time), complete two major activities in deploying beacons for way-finding and the accuracy of locating the PoIs on the indoor path of shopping complex floor plan given in figure 5.1.

Learning, adding beacon markers and drawing graph time are recorded in seconds. Total time to complete all the activities is the sum of adding beacon markers and drawing time.

Accuracy is shown in terms of three different values. Firstly, markers that are added correctly on the right PoI. Secondly, PoIs that should have ideally identified as a potential location for beacons but are missed and thirdly, markers that are redundant i.e., it either covers no PoI or is added on a PoI that is already covered by another beacon marker. Thus, accuracy can be measured as a combination of these three factors. This term is directly related to time taken to add the markers; lesser the time taken, lesser is the total number of PoIs identified. Therefore, this leads to higher chances of missing PoI. Similarly, higher redundant markers denote higher adding marker time.

Table 5.2 shows the time taken by 3 users out of 10 to perform the same set of activities on a larger floor plan shown in figure 5.2 except this time the users did not have to learn how to use the tool as they were familiar after the first set of evaluation.

Table 5.3 shows the results for the detection of PoI for Shopping complex floor plan shown in figure 5.1 along the indoor walking path using the IBeaconMap.

Similarly, table 5.4 shows the results for the detection of PoI for Large campus floor plan shown in figure 5.2 along the indoor walking path using the IBeaconMap.

Figure 5.3 to 5.6 show the time and accuracy for both web tool and ibeaconmap in pictorial form. The major highlight here is the difference in average time taken to perform the task manually

TABLE 5.1

TIME AND ACCURACY OF LOCATING POI, MARKING THEM AND CREATING CONNECTIVITY GRAPH ON SHOPPING COMPLEX (INDOOR PATH ONLY) FLOOR PLAN USING THE WEB TOOL.

User	Learning (s)	Adding Markers (s)	Drawing Graph (s)	Correct	Incorrect	
					Missed	Redundant
A	1180	490	900	46	3	4
B	370	427	783	43	6	2
C	600	350	818	41	8	1
D	-	129	403	27	22	0
E	912	738	921	48	1	6
F	240	312	761	36	13	2
G	447	392	681	41	8	2
H	735	353	724	39	10	1
I	563	648	994	47	2	3
J	701	542	801	45	4	3

on the web tool vs IBeaconMap. Also, the accuracy is much better in the result obtained using IBeaconMap. One place where we the web tool dominates IBeaconMap is the number of redundant markers placed when done by the user manually is much lesser than IBeaconMap.

With this result we can clearly state that for a simpler floor plan accuracy can be increased significantly by locating and marking the POIs manually but for a larger and complex floor plans, an automated mechanism is more useful as the processing time for doing this is really huge and can sometimes end up poor accuracy.

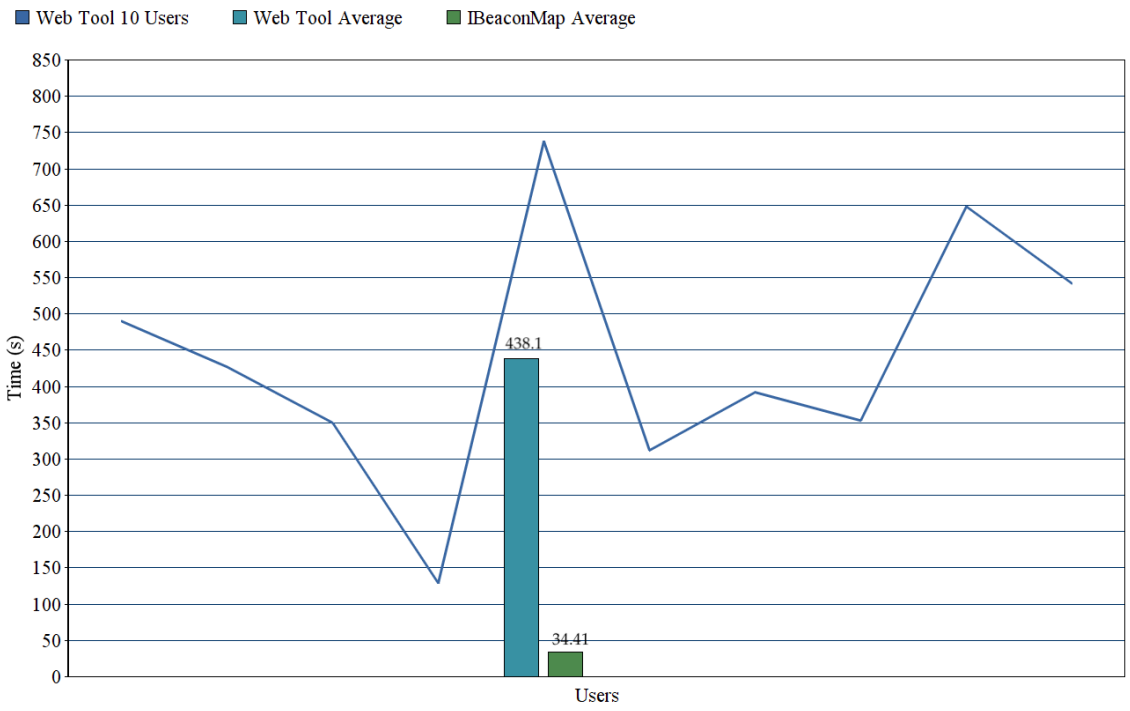

Figure 5.3: Average time to place beacon markers for shopping complex - Web tool vs IBeaconMap

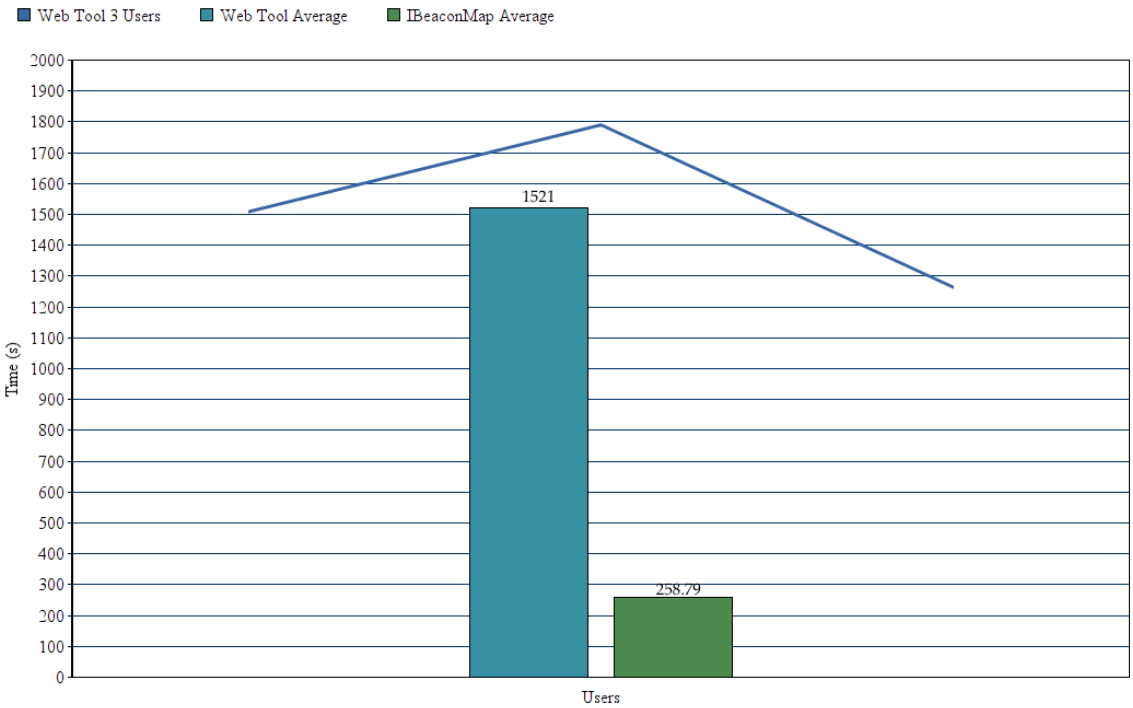

Figure 5.4: Average time to place beacon markers for large campus - Web tool vs IBeaconMap

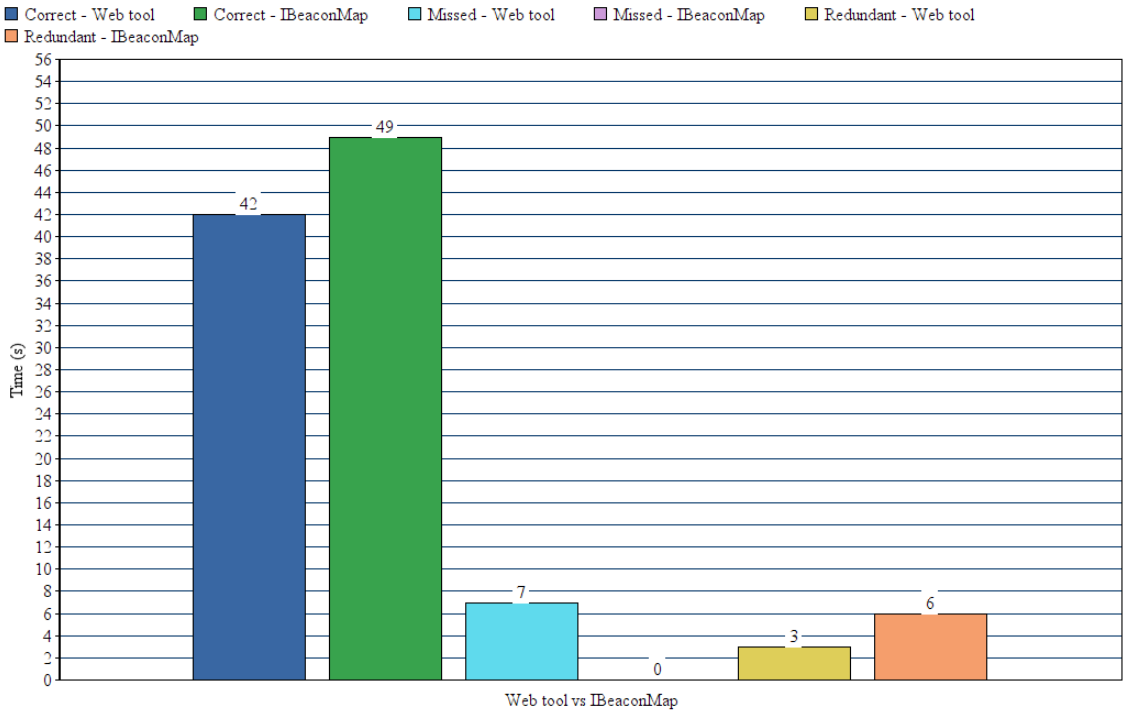

Figure 5.5: Accuracy for shopping complex - Web tool vs IBeaconMap

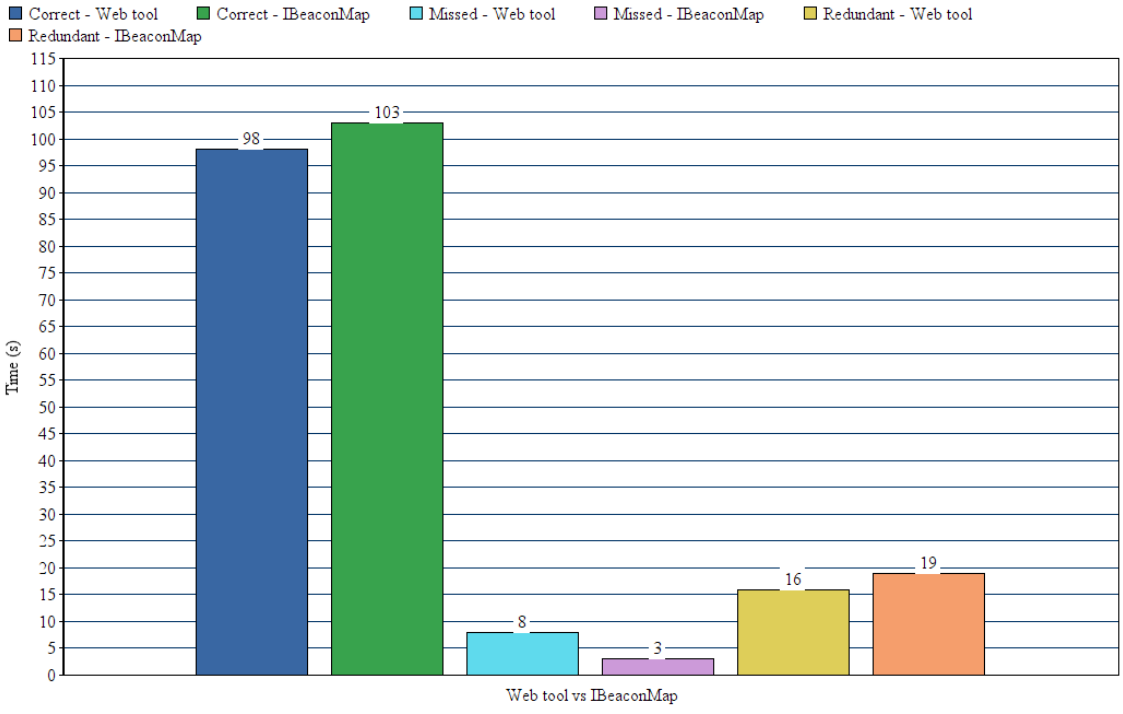

Figure 5.6: Accuracy for large campus - Web tool vs IBeaconMap

TABLE 5.2

TIME AND ACCURACY OF LOCATING POI, MARKING THEM AND CREATING CONNECTIVITY GRAPH ON LARGE CAMPUS (INDOOR PATH ONLY) FLOOR PLAN USING THE WEB TOOL.

User	Adding Markers (s)	Drawing Graph (s)	Correct	Incorrect	
				Missed	Redundant
A	1509	3278	99	7	20
B	1790	∞	101	5	23
C	1264	2815	94	12	4

TABLE 5.3

AVERAGE TIME AND ACCURACY OF LOCATING POI ON SHOPPING COMPLEX (INDOOR PATH ONLY) FLOOR PLAN USING IBEACONMAP.

IBeaconMap	Processing Time (s)	Correct	Incorrect	
			Missed	Redundant
	34.41	49	0	6

If only there was be a mechanism to switch between automated and manual marking methods based on the floor plan, it could result with a right trade off between accuracy and processing time that could in turn lead to maximum efficiency.

Generating graph process can be automated as well as we see for a larger floor plan, user C could not complete the activity and gave up the task half way. Even for other users, the amount of time taken to complete this is really huge. It can no way be done manually multiple times on different floor plans with similar complexity.

TABLE 5.4

AVERAGE TIME AND ACCURACY OF LOCATING POI ON LARGE CAMPUS (INDOOR PATH ONLY) FLOOR PLAN USING IBEACONMAP.

IBeaconMap	Processing Time (s)	Correct	Incorrect	
			Missed	Redundant
	258.79	103	3	19

5.2.2 User Comments

Table 5.5 shows comments given by users after completing the evaluation process for both the floor plans.

5.2.3 Scope of Automation

Based on the result given in table 5.5, both time taken to perform activities and user opinion, it can be assumed that marking beacons does not take much time and can be considered more accurate when done manually, as even if it is automated the chances of making the changes once beacons are marked automatically are very high as it is probably that not every door or other POI on the floor is useful for people with disabilities. Also, there could be other places on a floor plan that might not be a true point of interest but could be good potential candidate for beacon placement. All these points and the time taken to perform this activity shows that this part of the deployment activity can be done manually on such a tool where beacon configurations are handled are handled automatically.

On the other hand, drawing graph to generate the indoor space graph representation including orientation details is a very challenging task. It is very time consuming and cannot be performed manually for multiple floor plans especially if the if the floor plan is complex. As show in 5.2 user C could not complete this task for a larger floor plan and just gave up the task half way. Similarly,

other users had a similar opinion for this activity, especially while working on the larger floor plan.

TABLE 5.5

USER FEEDBACK ON THE TOOL AND BEACON DEPLOYMENT ACTIVITIES.

Floor Plan	User	Comments
Shopping Complex	A	Marking beacons were okay but graph was awful.
	B	Instructions were good.
	C	Adding compass orientation for graph edges was very painful.
	D	Not sure if I did it correctly; it was confusing.
	E	It was good. I loved the tool. Drawing graph was a bit tough.
	F	Had tough time finding the right orientation for graph edges.
	G	Added some more markers while drawing graph. Video instruction is better.
	H	Connectivity graph can be generated automatically.
	I	Drawing graph was not easy. Fixed compass orientation several times.
	J	Not sure if the connectivity graph is correct. It was time consuming.
Large Campus	A	Paused multiple times. I barely finished the tasks.
	B	Gave up while drawing graph, very tough to draw all the connections.
	C	Skipped compass orientation for most of the connectivity edges.

CHAPTER 6
CONCLUSION AND FUTURE WORK

This work presented a detail work flow of beacon deployment process and a web tool to do to represent indoor space into usable database graph for beacon-based way-finding for the BVI and other sighted users. Such a technique solves the current challenge of creating indoor space representations in a time and labor-efficient manner. The tool simply takes a floor plan of the indoor space under consideration and employs a step by step process to mark POIs and create the indoor space graph representation. Evaluations show the tool is useful to create accurate deployment infrastructure for beacon-based way-finding. Also, result shows highly labor intensive task that can be automated to make this tool versatile. The actual placement of beacons can then be done very easily, not even requiring skilled technicians. The merits of such a tool lies not just in how it makes beacon planning easy for new deployments, but also the maintenance features it provides in making future changes and alterations.

With this study we can conclude that there needs to a way to perform deployment activities both manually and automatically. As for a simple floor plan, it is quite easy, efficient and accurate to upload the floor plan and add the beacon location manually. As and when the floor plan gets bigger and bigger, it is extremely important to have a mechanism like IBeaconMap to automatically locate all beacon points. These points can always be corrected manually if needed.

However, drawing the connectivity graph can be completely automated as once the beacons are placed, it is quite evident how the connections are going to be between them. For cases where two or more beacons are connected to two or more beacons forming a loop, there can be option provided for the admin to clean the errors in the connections that are generated automatically.

There are several areas where this work can be expanded. We highlight some of them here. As an extension, such tools can handle 3D floor plan prints to tackle challenges associated in knowing beacon mount height. Smart Beacon tuning and maintenance can be potential area to work in

future. Advance machine learning techniques can be implemented to handle different situation and beacons can be remotely tuned based on the crowd and other factors which can fluctuate RSSI value received on the phone.

Information associated to a beacon is another area which carries huge potential. The tool can be further refined to handle information provided to each beacon in such a way that the tool intelligently breaks down the information into several layers based which is then delivered in the same sequence to the user. By using cutting edge machine learning technologies information can be constructed in such a manner that is it easy for the users can ask for more information and the system delivers the next level information based on priority.

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