T.C.
MARMARA UNIVERSITY
FACULTY of ENGINEERING
COMPUTER ENGINEERING DEPARTMENT

CSE497-Project Specification Document

Title of the Project

BLUETOOTH LOCALIZATION

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Group Members

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1. Problem Statement

Localization has started to take an important place in our lives [1]. GPS and other satellite technologies are used for outdoor positioning and such technologies locate assets with 10 meters error. Although it is tolerable for outdoor positioning, it is too high for indoor positioning. To be able to locate assets indoor with higher accuracy, we need Indoor Positioning Systems (IPS). In this project, we will work on IPS using Bluetooth Low Energy (BLE).

2. Problem Description and Motivation

Due to the increase in the number of large and complex buildings such as malls, companies, museums, warehouses and airports, security and wayfinding starting to become enormous problems. In a company, a visitor may enter an unauthorized area. In this case, a security guard can observe the behavior of the visitor, take the necessary action and/or report the visitor. It is a well known fact that in malls, people are wasting too much time to find the specific store they are looking for.

“Indoor localization is the process of obtaining a device or user location in an indoor setting or environment [1].” Many systems have been developed since this problem arose. Such systems are based on several technologies like Wi-Fi, computer vision, and sound waves. Each technology has some disadvantages. Computer vision based systems are too expensive. Systems that use sound waves for localization have short range. Although a Wi-Fi based system uses many access points, it still has low accuracy. Another approach to this problem is combining some systems in order to achieve higher accuracy. But these systems tend to become more complex and expensive. Bluetooth Low Energy technology has recently started to be used with IPS. Being highly cost-effective and more accurate, such innovation has pleased this part of the field. This advantage distinguishes it from other systems.

3. Aims of the Project

Primary aim of the project is to design an Indoor Positioning System. Specific aims of the project are listed below.

- Implementing location-finding algorithm(s) that uses the collected data by receivers at known positions in the IPS (BLE 4.1/BLE 5.1) and gives the position(s) with 2 meters error margin.
- Providing a heat map by using results (positions) which come from location-finding algorithm(s).
- Providing user-trace feature by using previous results saved in database. There are two different display ways, displaying trace visually like in the heat map and verbally like in the log record.
- Providing a navigation for people by using wayfinding algorithm(s).
- Providing an interface to show live locations, heat maps and detailed user traces.
- Evaluating the performance, accuracy, benefits and disadvantages of algorithm(s) designed for IPS (BLE 4.1/BLE 5.1).

4. Related Work

In the work of Chouchang Yang and Huai-Rong Shao [2], authors worked on Wi-Fi based IPS. In this system, devices that are desired to locate should have Wi-Fi capabilities. For positioning, they have used two types of localization approaches: Angle of Arrival (AoA) and Time of Arrival (ToA). If there is one Access Point (AP) nearby, they applied ToA method. Otherwise, they applied AoA method to obtain higher accuracy. They used Round Trip Time to measure distance between transmitters and receivers. On the other hand, they obtained the angle via AP which has multiple antennas. Performance of the AoA method increases with respect to number of antennas.

In the work of Cheng Zhou, Jiazheng Yuan, Hongzhe Lou and Jing Qui [3], authors proposed an indoor positioning algorithm based on Bluetooth Low Energy 4.0. They divided the problem into three phases: Collecting Bluetooth signals, Bluetooth signal propagation model, real-time position output. In the first phase, they are collecting Bluetooth signals and calculating the distance between receiver and transmitter using RSSI values. Main idea of second phase is improving the accuracy. They erase obvious errors and smooth the RSSI using Kalman Filters. In the third phase, using Kalman Filters, weighted least square and four border positioning they estimate the positions.

In the work of Cemin Zhang, Michael Kuhn, Brandon Merkl, Aly E. Fathy, Mohamed Mahfouz [4], authors worked on Ultra Wideband (UWB) IPS utilizing time difference on arrival (TDOA). They experienced this system for both 1D and 2D localization. In the 1D experiment, using 1 receiver and 1 transmitter they located the assets with less than a millimeter error. In the second experiment, they used 3 receivers which are put at know positions and 1 transmitter. They used TDOA technique and triangulation method to indicate the position. For the 2D experiment, they located the transmitter with an error of 1.68mm.

5. Scope of the Project

A real time positioning system has to locate assets in a duration that varies depending on the environment. If the system is an IPS, it also has to have high accuracy. Thus, the capability of an IPS can be evaluated under two headings; reliability and speed of the communication methods that are used in the system, accuracy of the indoor positioning algorithms. In our project, we want to design a cost effective IPS that satisfies these terms using Bluetooth 4.1.

Accuracy is the key point of an IPS. Therefore, we want to improve the system’s accuracy as much as possible. But we do not want to increase the cost too much. Thus, while improving the system’s accuracy, we do not plan to design or enhance any kind of hardware. Instead, we will focus on designing more efficient and more accurate indoor positioning algorithms than previously proposed algorithms.

The system will not be useful if it can not locate assets in a reasonable duration even though it can locate them with perfect accuracy. Therefore, we plan to improve the communication methods by:

- Increasing size of the packets which are sent from transmitter to receiver.
- Choosing more feasible communication technologies.

In real world, there are many complex buildings that are challenging for indoor positioning. We may face lots of issues when set up an IPS to these kind of buildings. Depending on the building structure, we may not be able to put the receivers at desired locations or due to the high signal interference, indoor positioning algorithms may have lower accuracy. In order to avoid these problems, we will design the IPS for a simple room. Therefore, our IPS may not be sufficient for such complex buildings.

When the localization part is done, we will have an IPS that produces valuable data. The data can be used for many purposes such as optimization and security. We plan to process the data in order to obtain:

- A heatmap that states crowded areas.
- Trace of individual users.

At this point, we will have three outputs: heatmap, user traces and real time locations. In order to make them easily observable, we will design a user interface on web.

Besides the main goals, we also have some claims:

- Assuming we get a Bluetooth 5.1 Angle of Arrival development kit at least two months before the project's deadline, we will implement an algorithm that can find the position of the target with 1 meter error margin.
- Assuming we managed to develop a position estimation algorithm for the IPS that uses Bluetooth 4.1, create heat map & detailed user traces, and design Web UI in planned time, we are planning to implement an Android application to display current location to user and provide way-finding feature.

6. Success Factors and Benefits

6.1. Success Factors

The project is aiming some success factors which are listed below.

- 95% of the estimated positions must have less than two meters error in the system based on Bluetooth 4.1.
- 95% of the estimated positions must have 1-2 meters error in the system based on Bluetooth 5.1.
- Wayfinding algorithm should give the optimal (shortest) path.
- User trace must display all routes that user passes and it must also give the specific time.
- For real time positioning systems, it is possible that delays may occur. Therefore, IPS should update the result on the real time positioning system in every 3 seconds.

6.2. Benefits

Indoor positioning systems have wide range of applications. Some of the potential benefits of the project are listed below.

- Real time location system used for many things such as security; e.g., a security guard can observe visitors easily by monitoring real time locations.
- Heat map can be used for optimization purposes; e.g., advertisers may analyze the heat map to find out most visited locations in specific areas of the buildings
- User track feature has many areas of utilization. In some cases, it can be a matter of life or death; e.g., in case of a disaster, a person’s last known position can save his/her life.
- Navigation feature saves time: e.g., a visitor can find the specific store they are looking for.

7. Methodology and Technical Approach

There are many methods that can be used to estimate the target's position. Some of the methods we plan to use are listed below.

7.1. Proximity

Proximity methods do not try to calculate real distance. Instead, proximity methods try to estimate relative position. The most primitive way is to check whether or not the object is in signal coverage. If more than one receiver node can see the object, pick one that has higher RSSI value.

7.2. Range Based Methods

Range based methods try to calculate the real distance between the receiver and the transmitter. These methods do not provide any information about the angle of signal. The most common techniques are using Received Signal Strength Indicator (RSSI) and Time of Arrival (ToA) a.k.a. Time of Flight (ToF).

In order to use ToA method effectively, exact time of signal arrival ($t_{arrival}$), time of signal sent (t_{sent}) and the speed of the signal (c) must be known. The speed of signal is usually taken as the speed of light. Then the distance (d) can be calculated with the equation [5]:

$$d = c * (t_{arrival} - t_{sent}) \quad (1)$$

The relation between RSSI and distance(d) can be expressed as [6]:

$$RSSI_d = (-10 * n) * log_{10}(\frac{d}{d_0}) + RSSI_{d_0} \quad (2)$$

where:

- d_0 : reference distance (usually 1 meter)
- d : distance desired to calculate
- $RSSI_{d_0}$: measured RSSI at reference distance d_0
- $RSSI_d$: measured RSSI at distance d
- n : coefficient depends on the environment

Since the value of n varies for different environments, it needs to be calculated in order to use the formula (2). At least two measurements are required for this purpose. Most common values of n are between 2.0 and 2.5. When the value of n is determined, the formula (2) can be used for distance estimations.

Whichever range based method is used, there will be no information regarding to angle. Only two things are known: position of the receiver, transmitters distance to the receiver. A possibility circle can be drawn with the information.

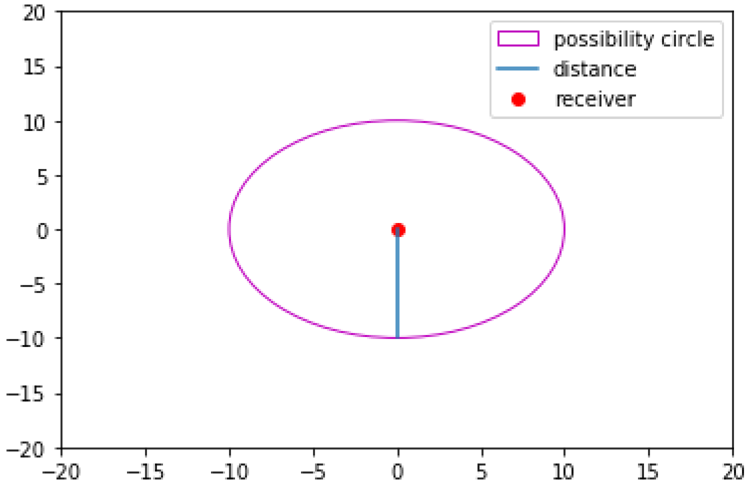


Figure 1: Possibility Circle

Using three receivers that are in different positions, three possibility circles can be drawn and center of the intersection points can be returned as estimated position of the transmitter. This method is called trilateration [7].

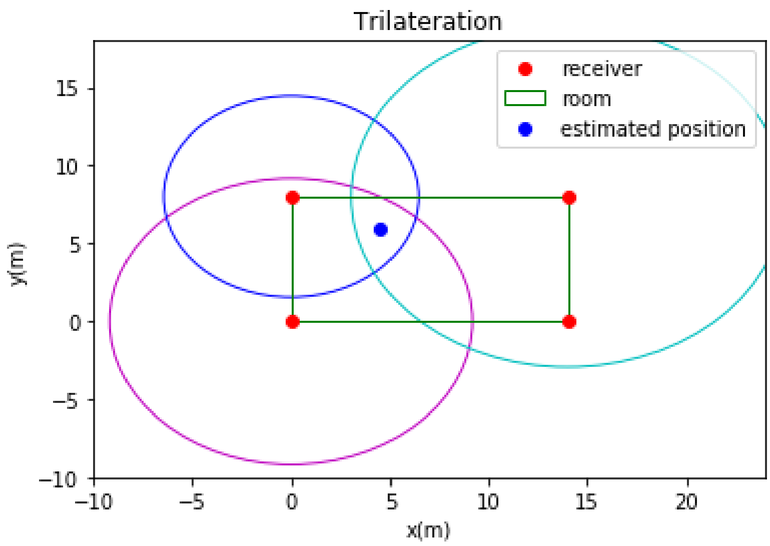


Figure 2: Trilateration example

7.3. Angle Based Methods

Direction finding feature comes with the development of Bluetooth 5.1 technology [8]. Instead of using distance, this method uses angle of signals. In order to use direction finding feature, system uses a specialized hardware that has multiple antennas containing receiver or transmitter. According to the position of multiple antennas there can be two distinct methods: Angle of Arrival (AoA) and Angle of Departure (AoD). If the receiver contains multiple antennas like shown in Figure 3, the method is called AoA. Otherwise like shown in Figure 4, it's called AoD.

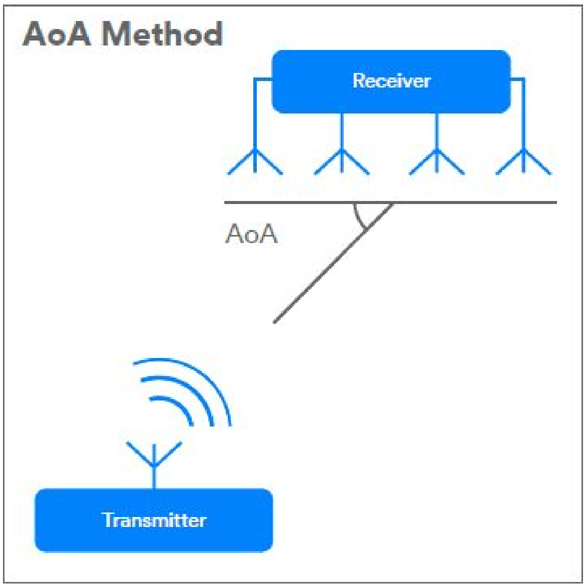


Figure 3: Angle of Arrival method from [8].

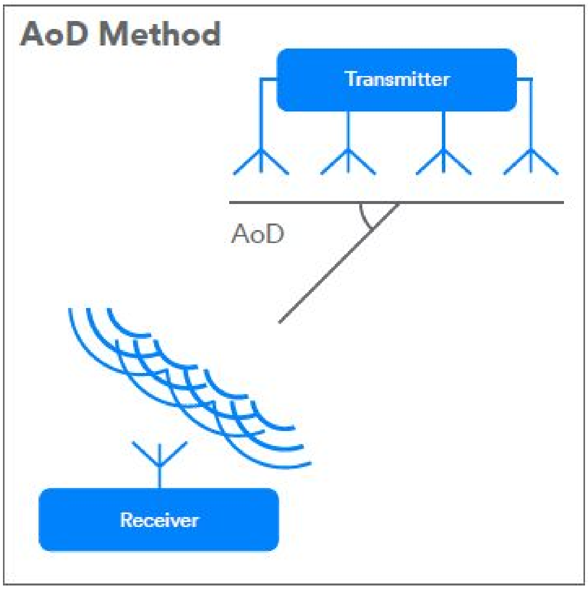


Figure 4: Angle of Departure method from [8].

Using two measurements from receivers at known positions, a transmitter's position can be estimated. This method is called triangulation [9].

7.4. Dead Reckoning

Dead reckoning based systems estimate current location of the target based on its last determined position. Using the last known position, speed of the target (can be measured using an acceleration sensor) and time difference between estimations, next position can be estimated. But inaccuracy of the process is cumulative [10]. Because new positions are calculated using the last determined location.

7.5. Fingerprinting

Fingerprinting [11] has two phases:

- Offline Phase: This is a preparation phase. Before using this method, points of interest should be picked and radio map of the area should be created. For each point data should be collected. This process is time consuming but increases the accuracy of the system.
- Online Phase: Also known as the localization phase. In this phase, system tries to estimate position of the target using collected data at offline phase. Characteristics of received signals should be compared with dataset and the most similar point should be determined. Widely used methods for comparison are:
    - Naive Bayes Classifier
    - k-Nearest Neighbors
    - Neural Networks
    - Support Vector Machine
    - smallest M-vertex polygon

The system we want to implement requires high accuracy. Proximity method is not feasible for high accuracy positioning. So, we are not planning to use methods like proximity method. We plan to implement two different positioning algorithms.

- First algorithm will be a combination of three methods discussed above. There will be a module for RSSI based algorithm, a module for dead reckoning and a module for fingerprinting approach. Combination of the results of these modules will conclude the final estimation. In figure 6, flow diagram of the system is represented by an UML diagram.

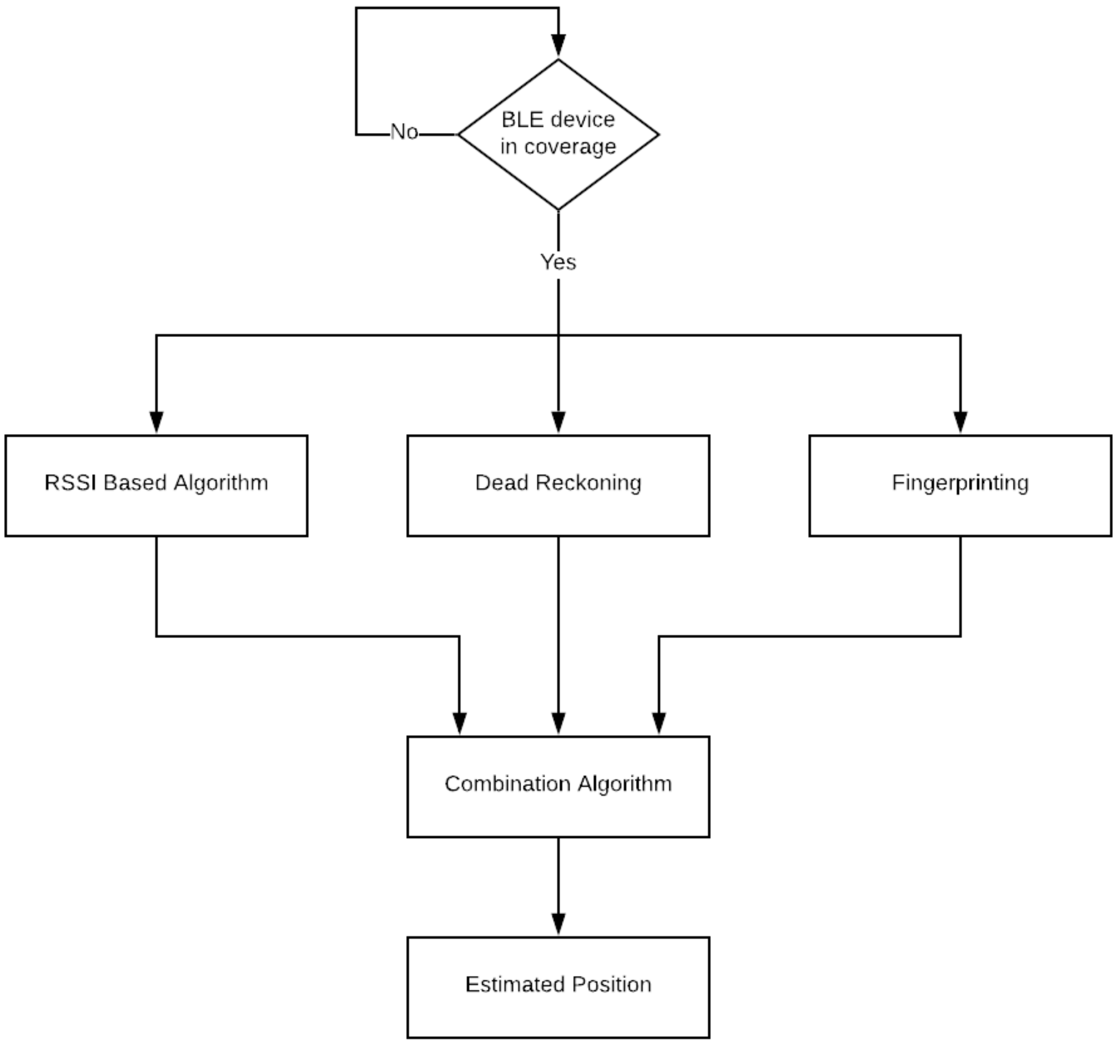


Figure 6: UML flow diagram of first algorithm

- Second algorithm will be based on Angle of Arrival (AoA). Using this new Bluetooth feature, we will implement a triangulation algorithm. In figure 7, flow diagram of the system is represented by an UML diagram.

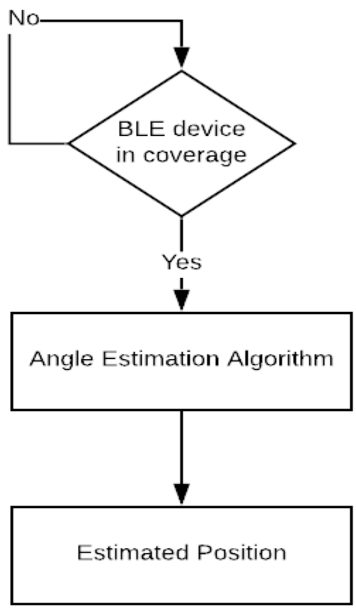


Figure 7: Flow diagram of second algorithm

We will be storing the results of positioning algorithms. By using this data, we will create a heat map that can show which areas are crowded. Also we will provide user traces that show a detailed activity history of the person/asset. We also plan to design a user interface on web that will show live locations on map, a heat map and user traces using Python/Django. Flow diagram of the system is represented by an UML diagram in figure 8.

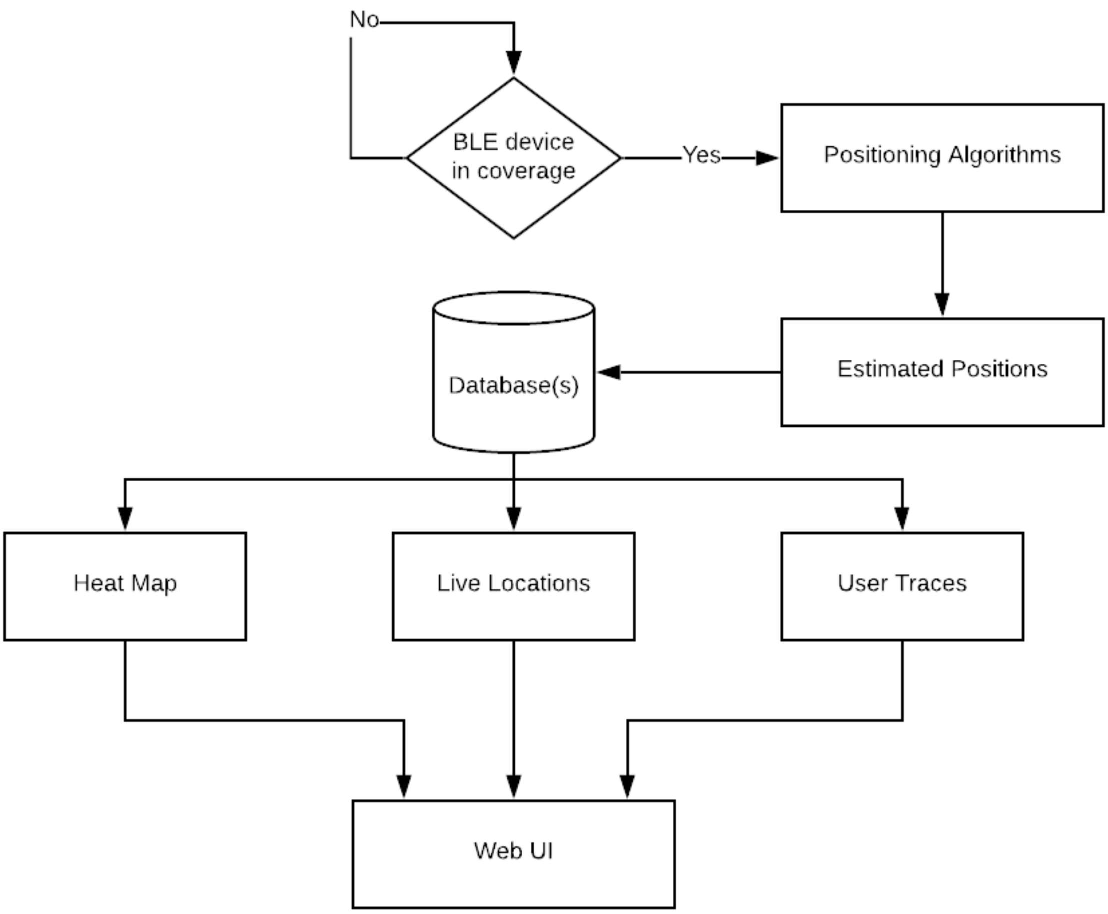


Figure 8: Flow diagram of the system

8. Professional Considerations

8.1 Methodological considerations/engineering standards

We are planning to use *Github* for source code control. All versions of the project will be accessible in the github repository. We also plan to use UML diagrams for better understanding over the source code/project. We are planning to code in python for designing algorithms, java for Android app, C/C++ for embedded, Django/HTML/CSS for Web UI, PostgreSQL for database part.

8.2. Societal/ethical considerations

8.2.1. Economical

Number of beacons and access points needed to place is varying depending on the environment. Since BLE beacons and access points are not expensive and easy to maintain, cost of this project will not be high for clients that we are targeting.

Using the heatmap feature, price of the billboards can be arranged, using the navigation feature, people can waste less time and a business can make profit.

8.2.2. Environmental

The project does not put environment in danger. We will be using BLE beacons as receivers and they consume low energy. For future generations, our project is nature friendly and consumes less energy which makes it beneficial and effective.

8.2.3. Ethical

The main aim of the project is to help people via localization and its features. The project will locate people only indoor. Our project will provide user traces only for the company that has the system. If a public place like a museum/mall uses this project, we will not collect or store any information other than device locations.

8.2.4. Sustainability

Bluetooth technologies are continuously supported and improved by the producers. A BLE Beacon battery can operate about two years with a button battery.

8.3. Legal considerations

All frameworks/programs that will be used during this project are open source. So, we will not need a license for developing tools.

In order to use some features of mobile phones for navigation, we need the permission of the user. The user will have to accept License Agreement to be able to use the system.

9. Management Plan

9.1. Description of task phases

Work Package 1: Requirement Analysis
Task 1.1: Literature research about indoor positioning systems that use Bluetooth Low Energy.
Task 1.2: Preparing Project Specification Document.

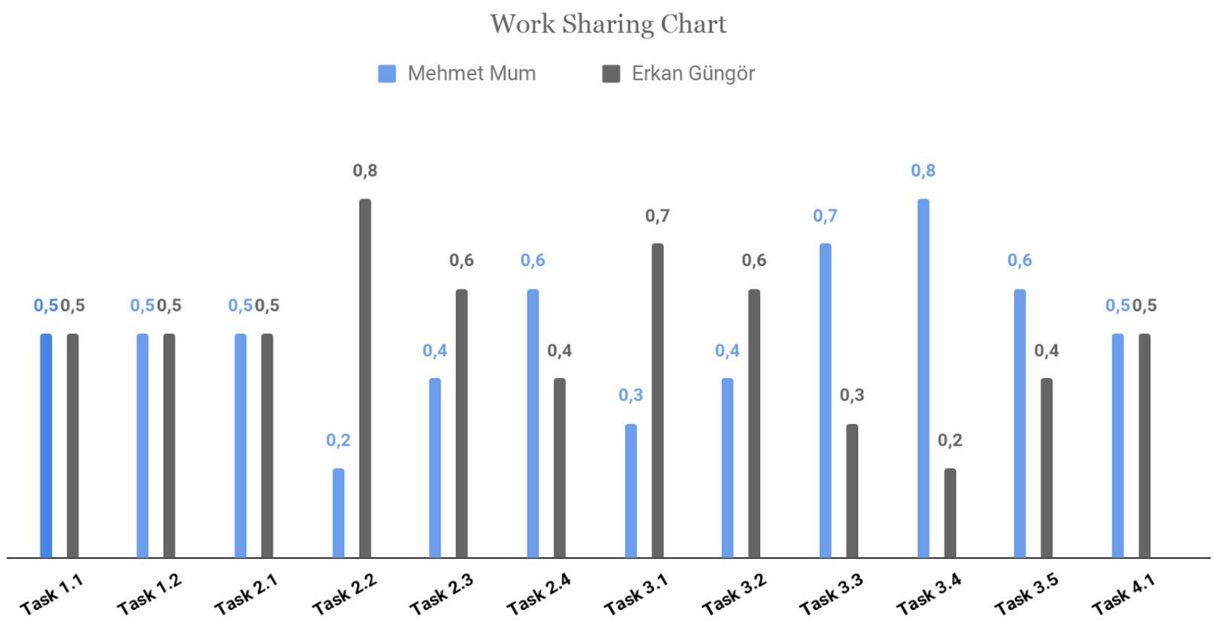
Work Package 2: Analyze and Design
Task 2.1: Researching and designing heat map and user trace using sample dataset(s).
Task 2.2: Designing WEB UI that shows real time locations, user traces and heat map.
Task 2.3: Setting up necessary hardware.
Task 2.4: Collecting and analyzing the data for better understanding over RSSI behavior.

Work Package 3: Implementation
Task 3.1: Implementing the three indoor positioning algorithms: RSSI based, dead reckoning, fingerprinting.
Task 3.2: Creating a simulation for testing implemented algorithms.
Task 3.3: Implementing indoor positioning algorithm for Angle of Arrival.
Task 3.4: Implementing android application for displaying user's own position and providing navigation.
Task 3.5: Implementing wayfinding path algorithm.

Work Package 4: Testing
Task 4.5: Evaluating our designed algorithms and comparing our improved system's performance with the previous one.

9.2. Division of responsibilities and duties among team members

Each team member is responsible for all task phases. However, the ratio of the responsibilities changes depending on the task. Roughly, task phases are divided as in the chart.


Work Sharing Chart
Mehmet Mum
Erkan Güngör
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Task 1.1
Task 1.2
Task 2.1
Task 2.2
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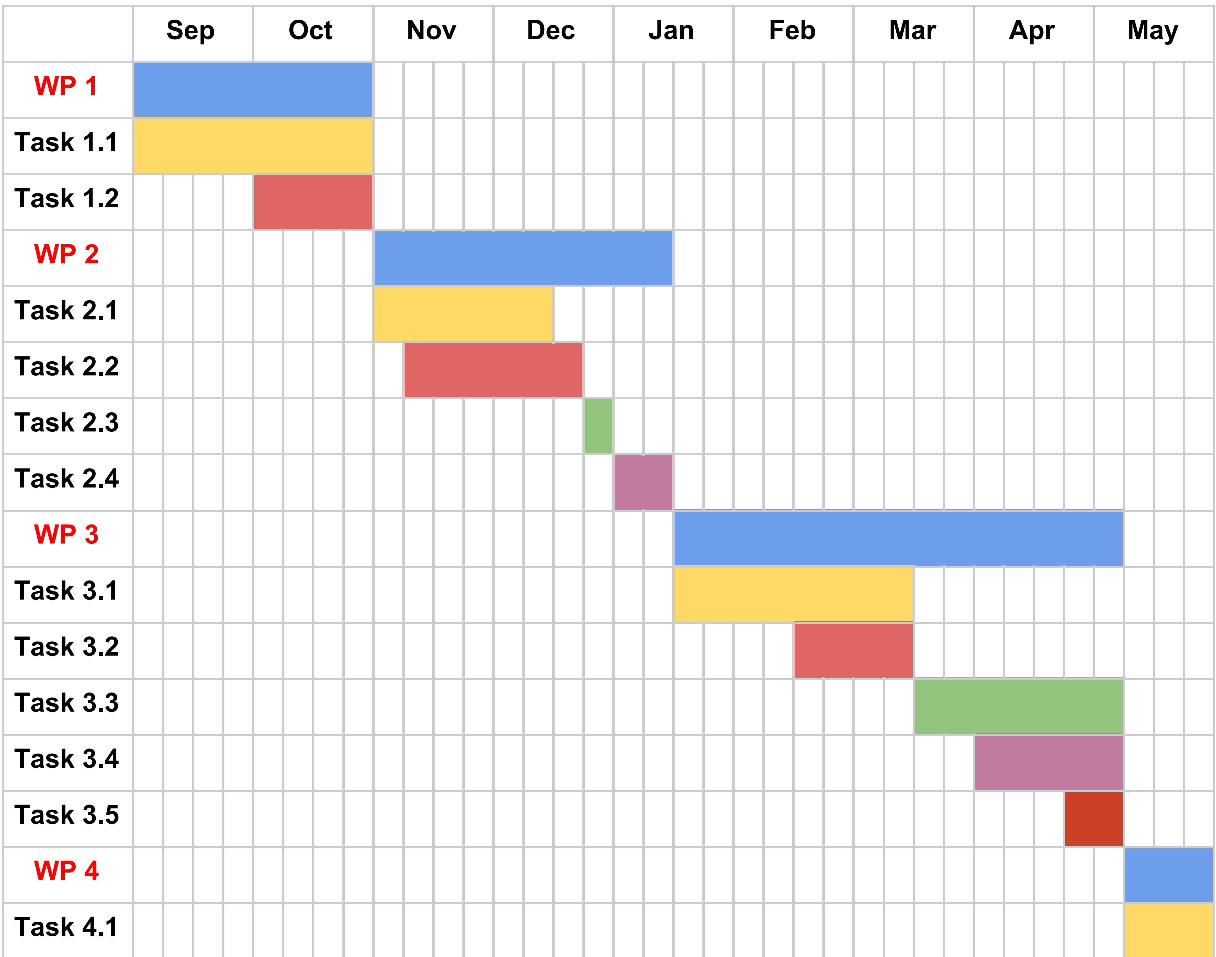
Task 2.4
Task 3.1
Task 3.2
Task 3.3
Task 3.4
Task 3.5
Task 4.1

9.3. Timeline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WP 1
Task 1.1
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WP 2
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Task 2.2
Task 2.3
Task 2.4
WP 3
Task 3.1
Task 3.2
Task 3.3
Task 3.4
Task 3.5
WP 4
Task 4.1

9.4. Risk management

- **Risk #1:** In order to estimate target positions with minimum error, RSSI values should be consistent. But bluetooth signal gets affected very easily from environmental factors. We might face inconsistent RSSI values.
  - **Likelihood:** Very high
  - **Predicted Solution:** For minimizing the error, receivers should collect RSSI values for a while to filter out outliers.
- **Risk #2:** Battery of the BLE Beacons may run out.
  - **Likelihood:** Low
  - **Predicted Solution:** This risk is very low because their batteries last about two years. Maintenance in every two years would be enough.
- **Risk #3:** In crowded environments, extraordinary RSSI values become more often.
  - **Likelihood:** High
  - **Predicted Solution:** Package sizes and propagation delays may cause this issue. Increasing package size or improving communication techniques may be a solution for this issue.
- **Risk #4:** Only a few companies are providing hardware that can be used for direction finding. We might not get the hardware on time.
  - **Likelihood:** Medium
  - **Predicted Solution:** AoA is not the core part of the project. If we can not get the hardware on time, we will update the schedule and keep working on Bluetooth 4.1.
- **Risk #5:** We have to put BLE Beacons on the walls of university buildings, and we must take permission to do it.
  - **Likelihood:** Low
  - **Potential Solution:** We can find somewhere else to put BLE beacons (houses, companies etc.) and manage the data collection part there. Then we can reschedule creation of the simulation and implement/test the algorithms on it.

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