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Honors Research Projects

The Dr. Gary B. and Pamela S. Williams Honors College

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Sports Spectator Beacon

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Honors Research Project

Personal Contribution

Alex Connelly

The report following details the research and design of the project titled “Sports Spectator Beacon.” My personal contribution to the project was in the area of core processing. I specifically researched multilateration equations that were to be used to track the beacon listed in the project and also helped to develop the back-end server that was used to transfer data between entities. I also helped develop the path loss model to be used. The model served to convert signal strengths into distances and was vital to ensure the accuracy of the system.

I also helped to research and develop the core processing code that received inputs and output a location for the beacon. This code is what was used to efficiently and accurately convert the data from the devices in this project into a realizable 3-D coordinate point location. Research was also done regarding the feasibility of this idea being implemented in a commercial process as well as how desirable this idea would be to a consumer.

Sports Spectator Beacon

Final Design Report

DT04

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12/01/2017

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Abstract

The objective of this design project is to develop a system that can determine the location of an implemented beacon. The main operating technique used in determining the location is RSSI multilateration. The system consists of a beacon, network transmitters, mobile users, core processing and an interface with each software component for data transmission. The beacon is only an RF transmitter; therefore, receivers need to be able to interpret the signal of the beacon. In order to determine the location of the beacon from the receivers, the locations of the receivers must be known. The network transmitters' act as a fixed grid to determine the location of the receivers and once that location is processed; multilateration is performed again to find the location of the beacon.

Problem Statement

Project Need

Where a football is located on a given play can be the determining factor between winning and losing a game. Whether the football position is related to a first down or a touchdown, the NFL and companies alike spend a fortune to ensure that accurate calls are made and the officiating crews do not rely solely on sight to make game-changing calls. Even with the current technology available, there are still times of discrepancy due to player interference or poor camera positioning. Therefore, an application that would allow multiple users to determine the location of a football is needed. Outside the context of a football application, a need exists on what is the obtainable resolution using multilateration. This project seeks to find the limitations of RSSI multilateration and the accuracy of location determination.

Project Objective

The goal of this senior design project is to design a system that will detect the location of a football within a certain degree of resolution. The system must be able to develop a coordinate grid of network transmitters to locate mobile users. The mobile application found on the user's mobile device must be able to connect to and determine signal strength from each of the network transmitters, to make a point in the established coordinate grid. The mobile application must also determine the signal strength of a transmitting beacon embedded within a football to determine its location. The system must also be able to interpret and process the mobile user data and perform necessary operations with such data. The embedded beacon must also not disrupt the integrity of the football.

Background

As stated previously, determining the location of the football is a challenging task for the officiating crew and those involved in the game. If an individual were to watch a football game, that individual would see how often calls are reversed or under scrutiny and this can create a lot of animosity between fans and players alike. Having the ability to remove the guessing and having a system that would give the user an accurate location of the football at all levels of play is what the sports spectator beacon is going to accomplish.

The NFL spends a fortune on data analytics using expensive cameras and other sensors during games to collect information. Digressing through the levels of football, most teams at lower levels do not have the same amount of technology as higher-level play. Through the I-Corps organization, 20 interviews were conducted of coaches, referees, and, athletic administrators to discover if there is a need for the sports spectator beacon in high school football games. The conclusion found is that high school football organizations are excited and interested in having more data available to them. Not having the access to this data often results in officials making uncertain calls and potentially changing the outcome of the game. Another finding was that the audience is interested in having more data at a high school level. A poll given at Kenston High School, seen in Figure 1, shows that over 75% of students are willing to download a mobile application that will bring more accuracy to the data obtained during the game. The design system as an alternative method of determining location will give all levels of play an option to help make the game and game preparation more accurate.

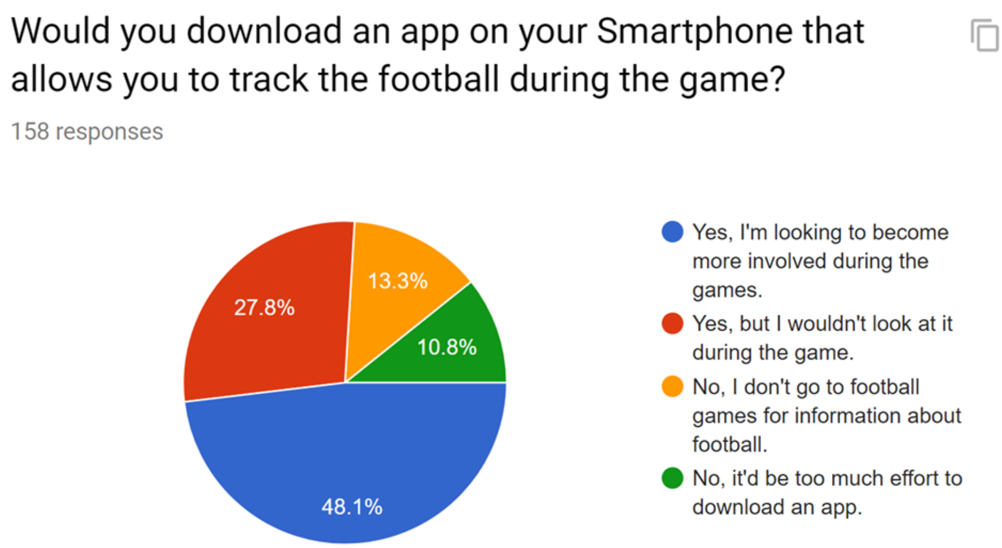


Figure 1: High School Mobile Application Download Count

Accuracy, however, is contingent on the mobile users associated with the game. The concept of this sports spectator beacon is to combine the audience with the game using a mobile application. Because this system is reliant on mobile users to create an array of receiving points, the resolution of the exact location is contingent on the users of this mobile application at a game setting. Figure 1 shows that out of 158 people roughly 119 of them would download the sports spectator beacon mobile application to provide more data for their teams. This is important because users need to use the application during the game so that the application can process the signals from the network transmitters and the beacon located in the ball.

The concept of using an array of mobile users as a method to detect a centralized beacon is a new direction to determining location of an object. In the application for the design system, the network transmitters act as a grid outline for coordinate system. Each network transmitter will maintain its unique SSID tag so the mobile application can distinguish various signals. The mobile application will measure the signal strength from each network transmitter. Thus, giving an array of known points to obtain the emitted signal strength from the beacon and conduct multilateration.

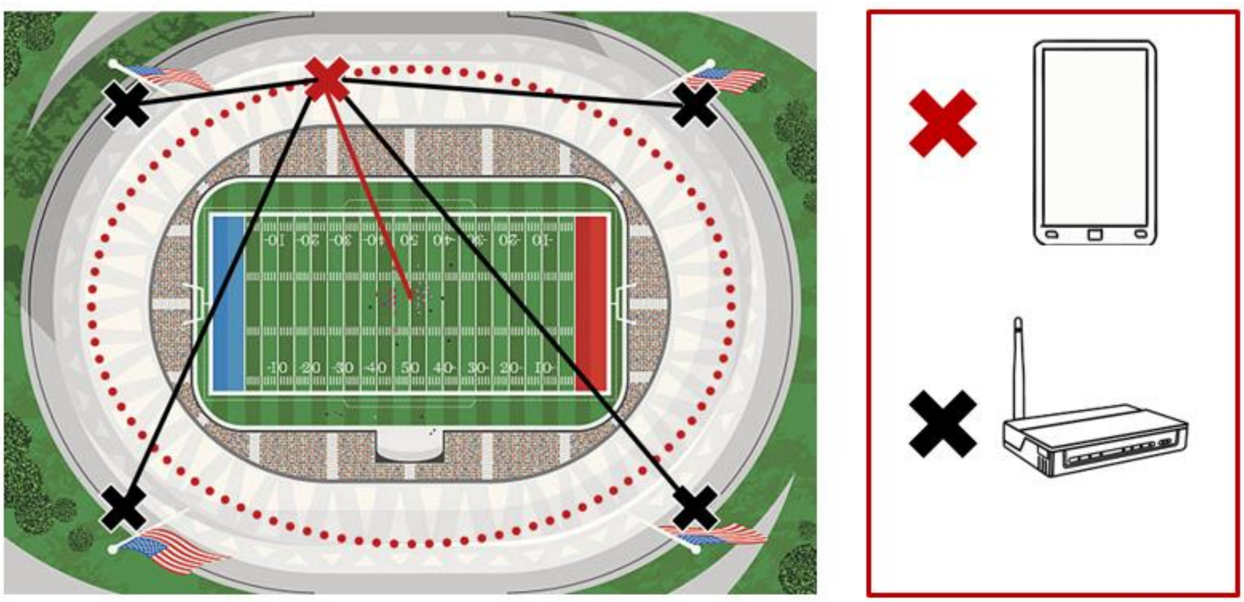


Figure 2: High-Level Figure of System During Final Operation

By measuring the signal strength of the beacon as seen by the mobile device, an array of devices can be created, each of which has its own signal strength information. The beacon should radiate a signal at 2.4GHz ideally with a quasi-isotropic antenna. An IEEE published article cited in the references shows the theoretical construction and testing of the antenna. This antenna is ideal because of its isotropic radiation pattern, which will result in easier and more accurate multilateration calculations. Using multilateration techniques here, the information can be used to calculate the specific area the football is located.

Design Requirements Specification

Creating a location detecting application should satisfy the needs of the end users in terms of determining location of the football; the technology will not interfere with the game based on internal integrity of the football and other external factors. The marketing and engineering requirements to ensure success in this project are as follows:

The development of a sports spectator beacon should provide the consumer with easily accessible data without disturbing the authenticity of the game. The following lists are descriptions of the marketing requirements and engineering requirements of the sports spectator beacon:

Definition and terms are as follows:

- Beacon: electronic device emitting a signal with a designated SSID.
- Mobile Device: the audience's smartphones measuring the beacon and network transmitter emitted signal strength.
- Network Transmitter: electronic device at set locations emitting a signal used for receiver location.
- Core Processor: a central unit that receives data from the receivers and determines the beacon's location.

Design Requirements

Marketing Requirements	Engineering Requirements	Justification
4,5	The beacon and network transmitter should emit a measurable signal at 2.4-2.5GHz.	The IEEE 802.11 wireless networking specification reserves 2.4 to 2.4835GHz for unlicensed industrial, scientific, medical services, and spread spectrum wireless data networks. This will allow the system to operate without interfering with other emitting devices in the area.
1,2	The beacon's total weight will be less than 15% of the football's total weight.	A regulation NFL football is manufactured by Wilson and weighs 14 to 15oz. The beacon, antenna, and harness should weigh less than 2.1oz. to avoid disrupting the weight and balance of the football.
3	The beacon's power supply should last 4 hours as the beacon consistently emits a measurable signal.	Under normal operation, the beacon should emit a consistent measurable signal throughout the duration a football game. As listed in the marketing requirements an average NFL football game lasts 3 hours and 12 minutes. To safely operate within this time the beacon should operate 4 hours after being fully charged.
6,7,8	The mobile devices involved will receive and identify the network transmitter and beacon's signal strength and SSID.	Each mobile device must receive and differentiate between the beacon and network transmitters emitted signals.
6,7,8	The mobile application will interpret the received signals on a dBm scale.	The power measurement will be in decibel-milliwatts a power ratio in decibels. This measurement scale is useful in measuring radio signals because it can express very large and very small values in a short form.
6,7,8,	The mobile application will sample the involved signals in 1-second intervals.	Sampling of the beacon's and network transmitter's emitted signal will occur every second. Faster sampling will be attempted, but 1 second intervals randomized between a large quantity of mobile devices should provide a sufficient number of signal strengths.

6,7,8,9,10	The core processor and mobile devices will interface with a server to transfer the data.	Each mobile device must communicate its received signal strength in decibel-milliwatts and time stamp to the core processor. A mobile application downloaded to the consumer's phone transmits the desired variables to the server.
6,7,8,9,10	The core processor will perform multilateration of signals.	The core processor uses the data from the mobile devices saved in registers to calculate the beacon's location. A specific software will conduct the multilateration on a designated computer.
7	Multilateration of signals will determine the location of the beacon with an error of 20% the ball's actual location.	A 20% error of the beacons known location is a measurable and useful degree of accuracy.
8	The network transmitters will be placed in fixed positions to locate the mobile devices within a defined area.	To determine the location of the mobile devices the network transmitters must be placed in known locations. The network transmitters need to be secured to avoid any movement so the mobile devices can be located consistently throughout the football game.

Table 1: Design Requirements

Marketing Requirements

1. *The beacon should not significantly change the weight of the ball.* For implementation in an actual game, the beacon cannot change the physical specifications of a regulation football. The hardware mounted inside the ball are to go unnoticed by the players and the beacons harness should protect the beacon from damage throughout the game.
2. *The beacon should not significantly change the center of gravity of the ball.* Football coaches were interviewed to obtain input about the sports spectator beacon's application. The coaches expressed concern about disrupting the balance of the football. The beacon must be mounted in a way that maintains the football's weight distribution.
3. *The beacon's power source should last the duration of a regulation football game.* An average NFL football games lasts 3 hours and 12 minutes. The beacon should be able to operate an entire football game.
4. *The beacon and network transmitters should emit signals within the legal specifications of the FCC.* The Federal Communications Commission regulates interstate communications by radio, television, wire, satellite, and cable. The beacon and network transmitters should operate safely in the legally allowed frequency ranges.
5. *The network transmitters should be non-obtrusive to the area of detection.* Interference with other signals will be avoided at all costs to reduce error within the system. Physically the network transmitters should be mounted to avoid any movement from their known location.

6. *The core processor should determine the beacon's coordinates.* Over a range of time, while the beacon is moving, its coordinates are saved in a register. A plot of the beacon's path correlates time to beacon's location.
7. *The core processor should determine the beacon's location to a useful degree of accuracy.* Obtaining the location of the beacon within a predetermined area will provide useful data for the officiating and user satisfaction.
8. *The core processor should determine the location of the mobile devices within a specified area.* The system must know the location of the mobile devices, which are receiving the emitted signals.
9. *The mobile application's interface should present the beacon's path clearly to the consumer.* Pertaining to the application in a football game, the consumer using his/her smartphone will know the location of the football during each play. This data is to be used to determine out of bounds, first downs, and touchdowns.
10. *The mobile application should be accessible on an Android operating system.* Roughly 51% of American and 70% of the world's smartphone sales are Android based mobile devices. The number of users and the open platform of Android mobile devices makes it a more enticing operating system than iOS by Apple.

Objective Tree

The Objective Tree below is a visual representation of the marketing requirements and their subcategories.

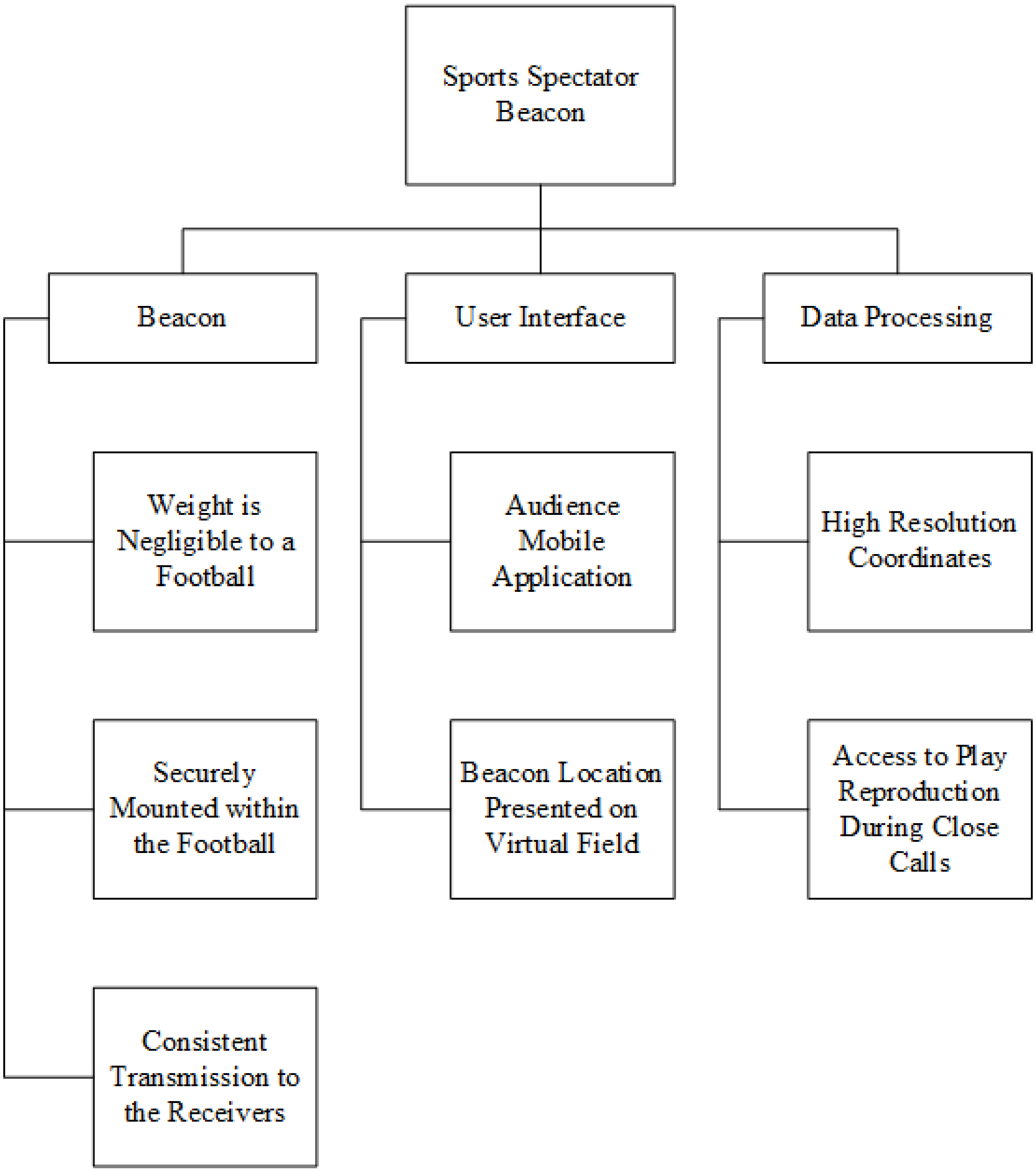


Figure 3: Objective Tree

Technical Design

Each aspect of the design is divided into the following sections:

A. *Beacon Transmitter*. Seeks to describe the applied beacon and its power and signal circuits necessary for use.

B. *Network Transmitters.* Seeks to describe the transmission methods of the wireless router, the power consumption and the configuration process.

C. *Signal Processing.* Seeks to describe the accumulation of data processing and how the mobile user's data will be formulated to locate the beacon.

D. *Software Design.* Seeks to describe the mobile interfacing between the varying transmitters and then developing the web-based network to evaluate and utilize the data that is involved in the transmissions.

A. Beacon Transmitter. (DCB)

Description

Theory of Operation

The beacon is a low power radio transceiver embedded in the football. Transceivers can receive and transmit data through radio signals. The currently application of beacon transceiver is to transmit the radio signal throughout the stadium. A receiver array within the stadium will then measure the signal strength of the emitted signal. The receiving capabilities of the transceiver will be used if needed upon further design. A correct selection of a radio frequency transceiver is critical to successfully tracking the beacon. The transceiver must be small enough so that it does not disrupt the weight and balance of the ball. Another aspect is the distance of transmission; a typical football field is 120 yards by 53.33 yards. The beacon must transmit beyond the football field throughout the stadium. A general requirement to satisfy and to reach many of the receivers is to transmit a 1000-foot radius from the center of the football field.

Engineering Calculation

- An NFL regulation football has the following specifications:
- Manufacturer: Wilson
- Material: Urethane Bladder Enclosed in a Pebble Grained, Leather Case
- Inflation: 12 ½ to 13 ½ pounds
- Long Length: 11 to 11 ¼ inches
- Long Circumference: 28 to 28 ½ inches
- Short Circumference: 21 to 21 ¼ inches
- Weight: 14 to 15 ounces

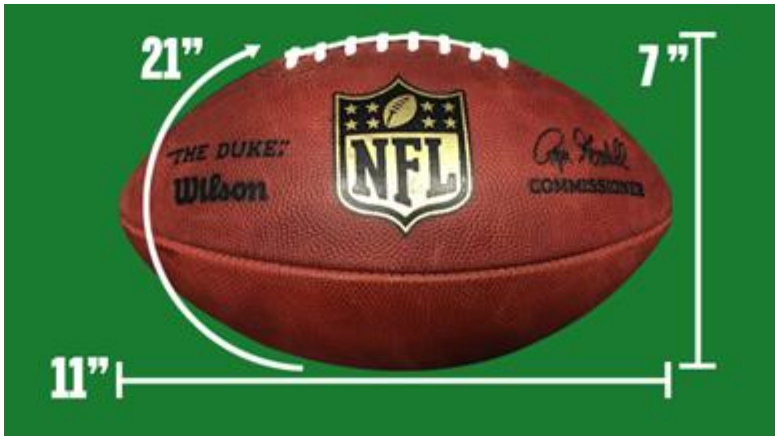


Figure A-1: NFL Regulation Football

Multiple football coaches and referees were interviewed to determine the marketability and application of the sports spectator beacon. Their main concern was with the about the weight and balance of the football with a beacon embedded inside. To make the product applicable in the real world the beacon’s weight must be less than 15% of the footballs total weight to avoid any disturbance in the weight or balance of the ball. During the design, a rule of thumb is that after embedding the beacon in the football the net weight should not exceed 16.6 ounces. The beacon consists of the electronics, antenna, and harness.

$$\text{Average Weight of a Regulation Football} = 14.5 \text{ oz}$$

$$0.1514.5 \text{ oz} = 2.175 \text{ oz}$$

$$\text{Net Beacon Weight} < 2.1 \text{ oz}$$

To avoid disrupting the balance of the football the beacon is placed in the center of the foot at its center of gravity. The main electronic components will be mounted at the center of gravity, depending on the chosen antenna its mounting will be later determined to avoid disrupting the footballs balance. While the antenna is going to be mounted as close to the center of gravity, its weight should be negligible. The harness is designed in a symmetrical pattern and will not unbalance the ball and it's rotation.

Football Center Radius:

$$r = \frac{C}{2\pi} = \frac{21.25}{2\pi} = 3.38''$$

Football Center of Gravity (COG):

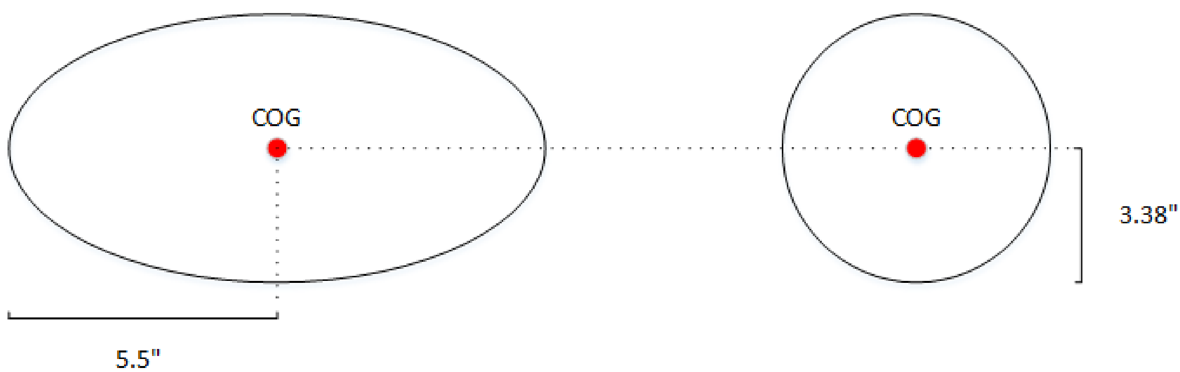


Figure A-2: Football Center of Gravity

Beacon 3D Harness:

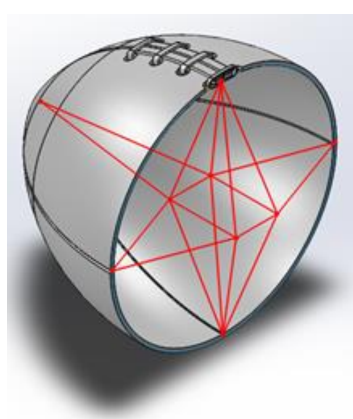


Figure A-3: Football Beacon 3D Harness View A

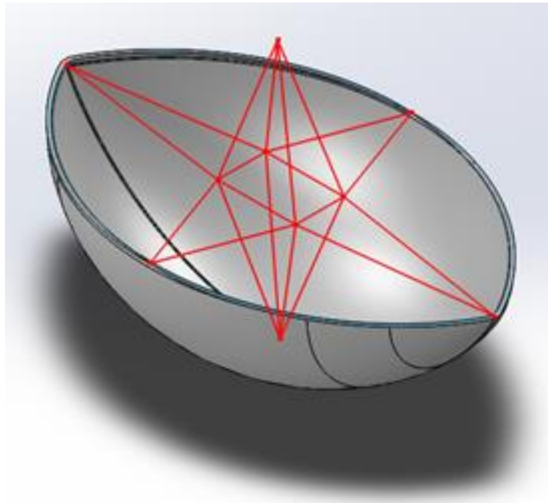


Figure A-4: Football Beacon 3D Harness View B

The antenna design is an important portion of the beacon because it determines the radiation pattern of the signal. When designing and writing the program for multilateration knowing the radiation pattern is critical. In an ideal situation, an isotropic antenna would be used. An isotropic antenna is a theoretical antenna, the benefit of this antenna is that it radiates in all direction with the same intensity. Figures A-5 and A-6 show the radiation pattern of an isotropic antenna. When trying to locate the beacon using this radiation pattern the calculations get simpler because the signal strength is the same at varying radii. Unfortunately, this is an ideal situation and the world is full of complications and limitations.

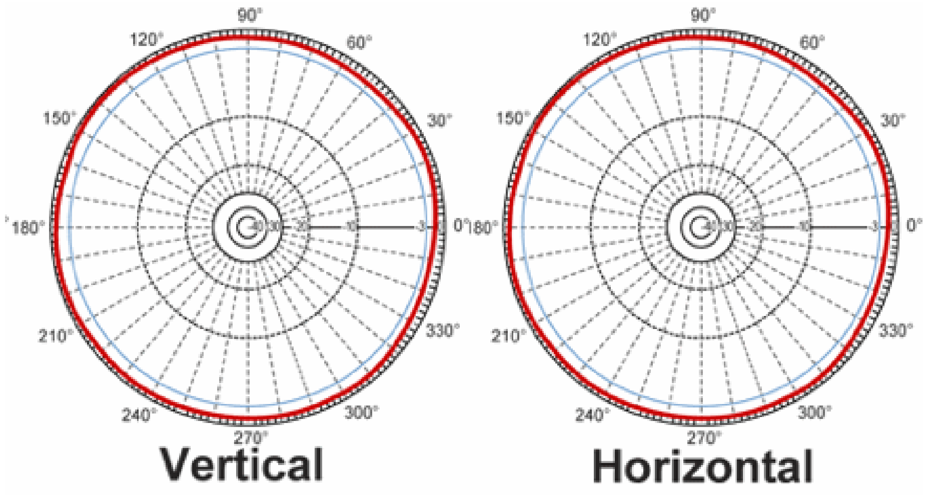


Figure A-5: Isotropic Antenna 2D Radiation Patterns

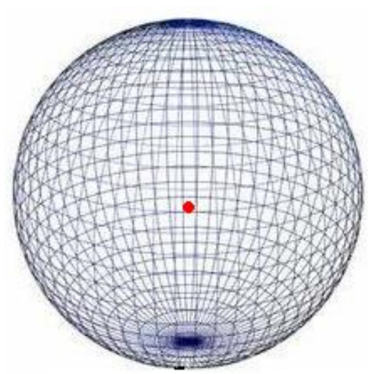


Figure A-6: Isotropic Antenna 3D Radiation Pattern

A quasi-isotropic antenna is the closest known antenna design to have a radiation pattern similar to the isotropic antenna. The quasi-isotropic antenna has a uniform radiation in all directions and the physical makeup of the antenna can be seen in Figure A-7 below. The antenna is constructed on flexible substrate making it ideal for implementation inside a football. Radiation patterns of the quasi-isotropic antenna are in Figure A-8. This would be the best practical antenna for the beacon.

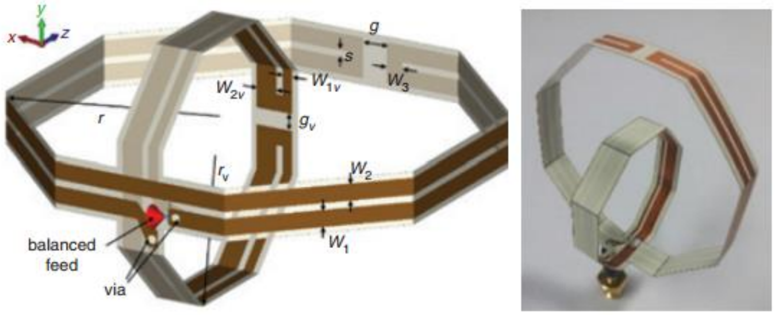


Figure A-7: Quasi-Isotropic Antenna Geometry

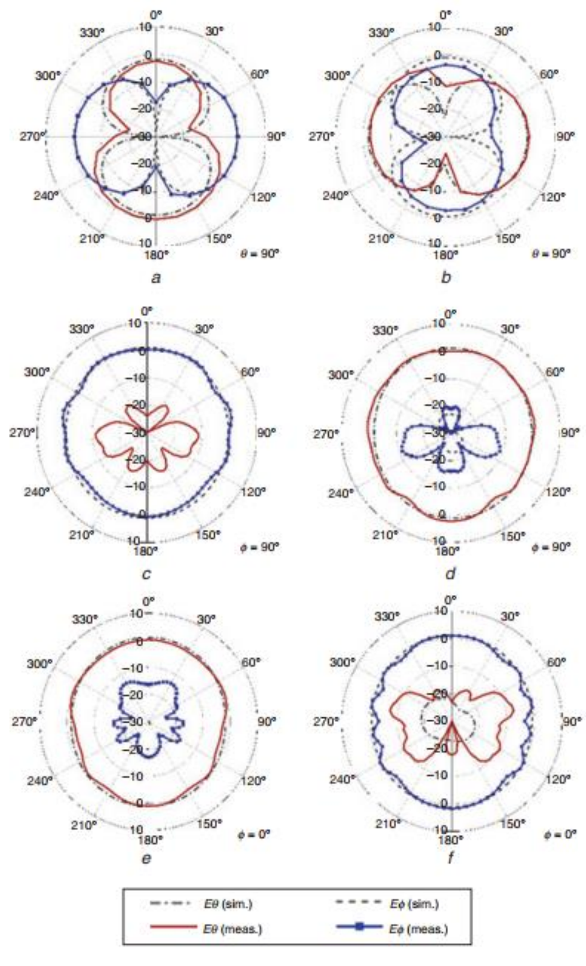


Figure A-8: Quasi-Isotropic 2D Radiation Patterns

While the quasi-isotropic is the best antenna, it is an experimental antenna and the reliability is questionable. The beacon is designed to support multiple antenna designs for a more robust system design. A dipole antenna is a standard antennas used throughout the modern world. The dipole antenna is very simple and at a basic level. It is a symmetrical wire with the electronics being connected to its center. The geometry of the dipole antenna is represented in Figure A-9. A major concern of all of the antennas is the radiation pattern shown in Figure A-10; the dipole antenna has a radiation pattern that looks like a donut. This results in complications when conducting multilateration because the orientation of the beacon must always be accounted for. The algorithms must be robust enough to vary with the constantly changing direction and orientation of the beacon and its radiation pattern.

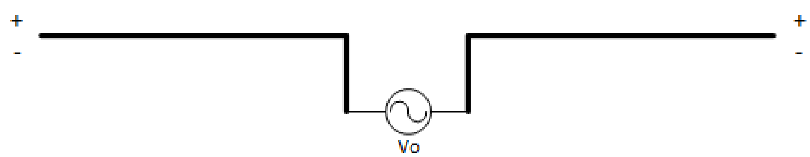


Figure A-9: Dipole Antenna Geometry

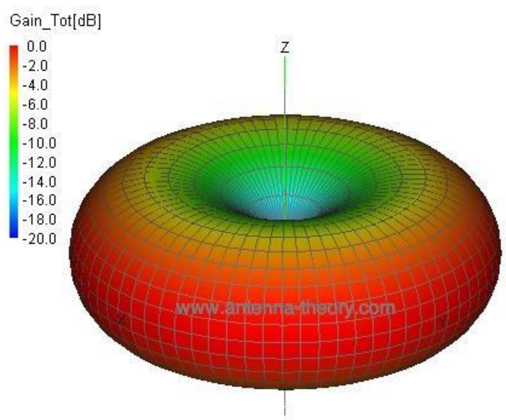
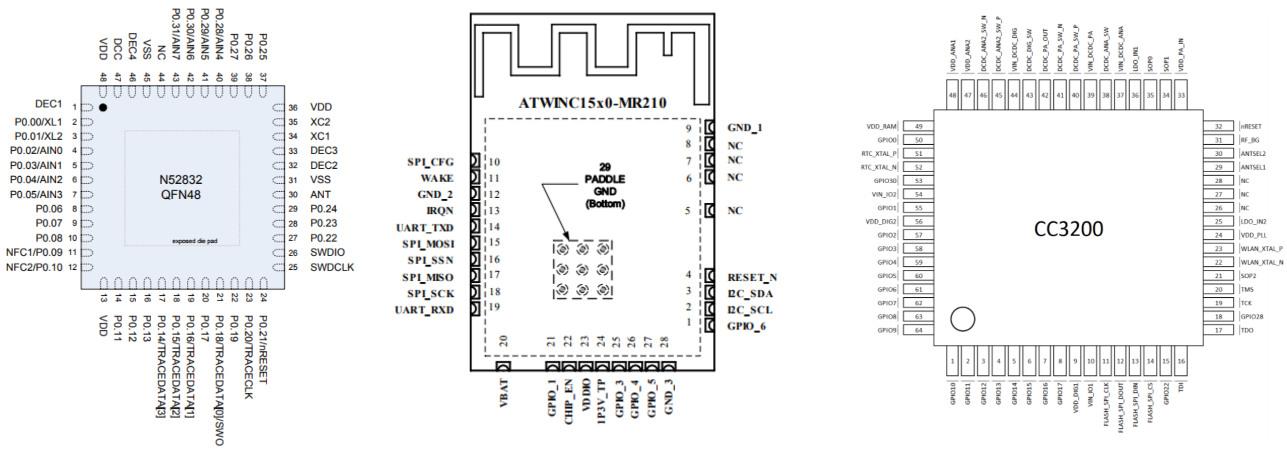


Figure A-10: Dipole Antenna; 1 Wavelength 3D Radiation Pattern

Now that the antennas are specified, they need to be supplied with an electrical signal that will be transformed into a radio frequency. This will be done utilizing a microcontroller unit with radio frequency capabilities. Currently two microcontroller units and a SoC are being considered; Texas Instrument CC3200, MICROCHIP ATWINC1500, and Nordic Semiconductors nRF52832. The microcontroller's pin layout is shown in Figures A-11, A-12, and A-13. As with the antennas, an ideal and practical design is proposed. The ideal situation is utilizing the Nordic Semiconductor Figure A-11, equipped with the quasi-isotropic antenna. The Nordic Semiconductor's SoC provides a 4dBs to the antenna with a peak current of 5mA during constant transmission. This will theoretically provide a spherical radiation at 2.4GHz, which will



be ideal for multilateration.

Figure A-11, A-12, A-13: From Left to Right, Nordic Semiconductor nRF52832, MICROCHIP ATWINC1500, Texas Instrument CC3200

The practical version that will be used in case the quasi-isotropic antenna does not work is the MICROCHIP MCU shown in Figure A-12. This MCU has a printed antenna, which radiates in doughnut shape somewhat like the dipole antenna's radiation in Figure A-10.

Finally, the power output of the antenna must be considered. As seen in the beacon's hardware block diagram a power amplifier and impedance matching circuit are in between the antenna and radio frequency transmitter. Usually radio frequency transmitters have internal power amplifiers, but the power amplifier may be needed if the antenna's natural gain is not high enough. The impedance matching circuit is implemented to allow for maximum power efficiency of the antenna. All of these options are implemented in the ideal beacon construction. The practical beacon construction has the power amplification and impedance matching included internally.

Hardware Block Diagram

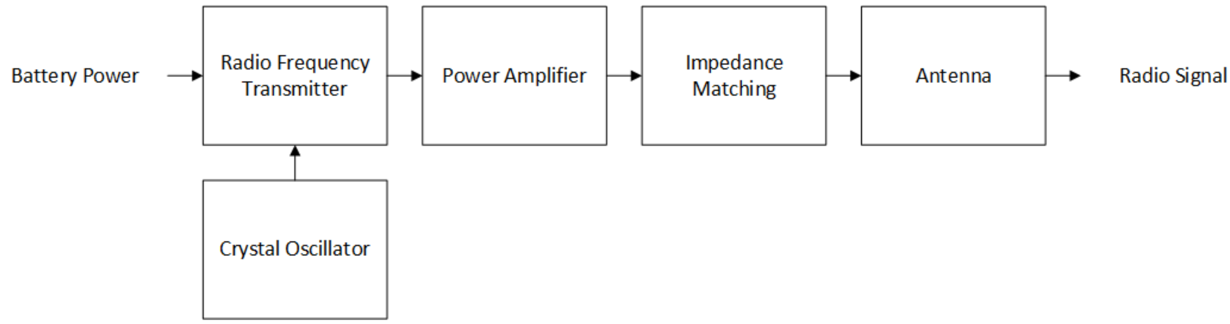


Figure A-14: Beacon Hardware Block Diagram

Hardware Functional Requirements

Module	**Radio Frequency Transmitter**
Inputs	DC Power (1V – 5V), Crystal Oscillator
Outputs	2.405 GHz – 2.475 GHz Electrical Signal
Functionality	The radio frequency transmitter's purpose is to generate the signal that is to be transmitted. Currently microcontroller units with radio frequency transmission capability are being researched.

Table A-1: Hardware Functional Requirements, Radio Frequency Transmitter

Module	**Crystal Oscillator**
Inputs	Radio Frequency Transmitter Internal DC Voltage
Outputs	Circuit Main Frequency
Functionality	An external crystal may be used to provide the radio frequency transmitter with a higher or designated oscillation. The oscillators are used to convert direct current (DC) to alternating current (AC). In radio transmitters, oscillators are used to stabilize the frequency.

Table A-2: Hardware Functional Requirements, Crystal Oscillator

Module	**Power Amplifier**
Inputs	DC Power (1V – 5V), Radio Signal
Outputs	Amplified Electrical Signal
Functionality	Radio frequency amplifiers drive the antenna of the transmitter by converting low-power frequency signals into higher power signals.

Table A-3: Hardware Functional Requirements, Power Amplifier

Module	**Impedance Matching Circuit**
Inputs	Electrical Signal (2.4 GHz – 2.475 GHz)
Outputs	Electrical Signal (2.4 GHz – 2.475 GHz)
Functionality	Impedance matching is required to ensure most of the power from the power amplifier is transmitted to the antenna. Basically, the antenna's impedance must match the transmission line.

Table A-4: Hardware Functional Requirements, Impedance Matching Circuit

Module	**Antenna**
Inputs	Radio Signal (Receiving), Electric Signal (Transmitting)
Outputs	Radio Signal (Transmitting), Electric Signal (Receiving)
Functionality	The purpose of the antenna is to act as the interface between radio wave propagating in space and electric signals in conductors. The two main antennas being considered is a quasi-isotropic and dipole antenna.

Table A-5: Hardware Functional Requirements, Antenna

B. Network Transmitters. (TCD)

Description

Theory of Operation

The purpose of the network transmitters is to develop a grid of coordinates to determine location of the mobile users. With the use of multiple network transmitters, the location of the mobile users is determined by the signal strength received from each network transmitter. Knowing the mobile phone must exist inside of the grid of coordinates, using multilateration of each signal strength will effectively determine the location of the mobile users. The interfacing of signals resides internal to the mobile device to determine the signal from the beacon embedded within the football. Therefore, in knowing the exact location of the mobile user becomes an important aspect of accuracy when determining the football's location.

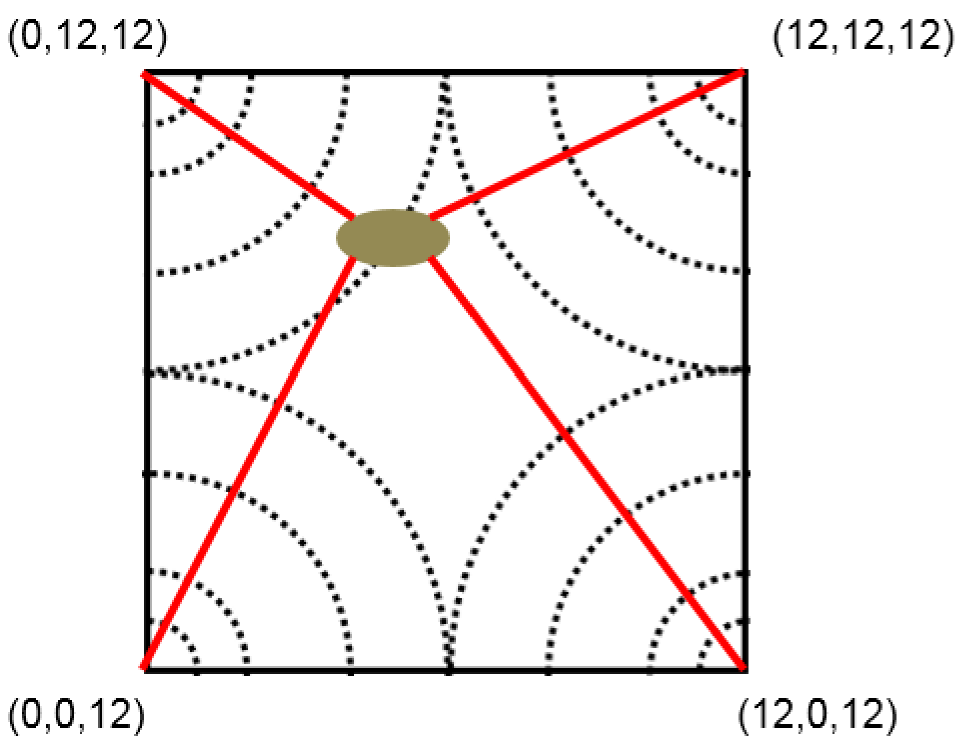


Figure B-1: Representation of System's Network Transmitters in Fixed Grid

The above figure is an idealistic representation of the Wi-Fi waveforms that would be transmitted across the grid of coordinates. At each corner of the grid is a network port. In the final application, the system does not have to be limited to only four network transmitters. In fact, the more network transmitters used in the application gives greater potential at receiving a higher resolution of the receiver's location. The system needs at least four network transmitters to overcome the three-dimensional volume when using multilateration of each transmission signal that is unique in the sense that the signal will maintain its own SSID tag.

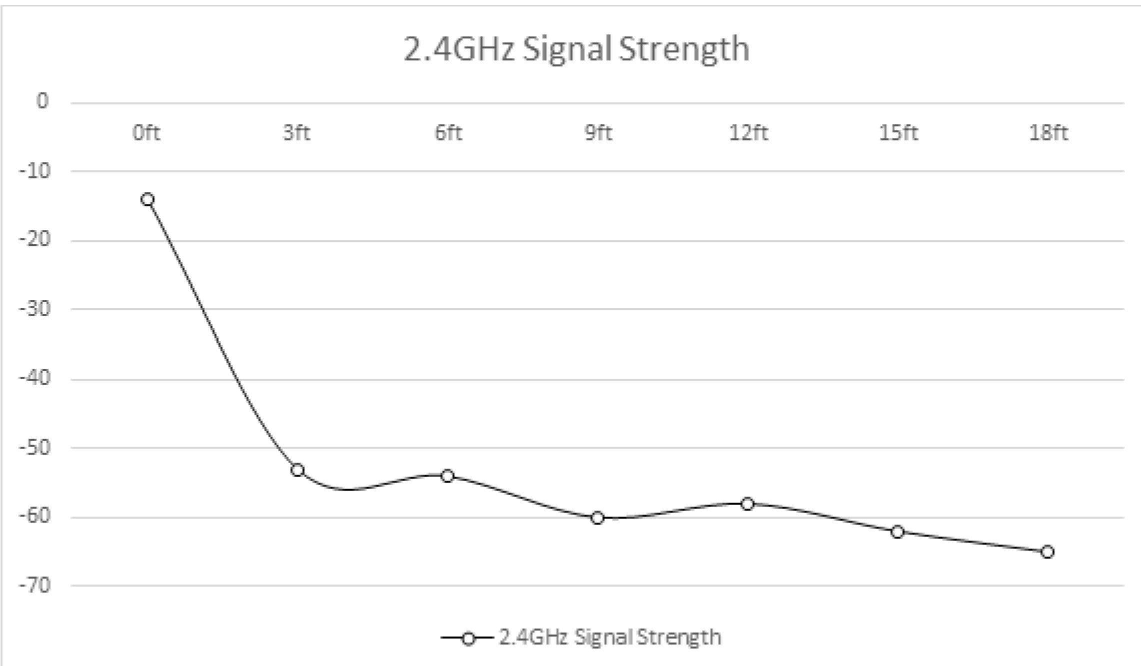


Figure B-2: Signal Strength Data Received from Network Transmitter

The Wi-Fi router that is to be implemented features two omnidirectional antennas. The configuration of these antennas creates a uniform horizontal distribution, but the vertical distribution is focused in primary and secondary lobes that are far from uniformity. In Figure B-

3, from the article, “Omnidirectional Antenna Radiation Patterns”, the figure shows the typical radiation pattern of real omnidirectional antennas.

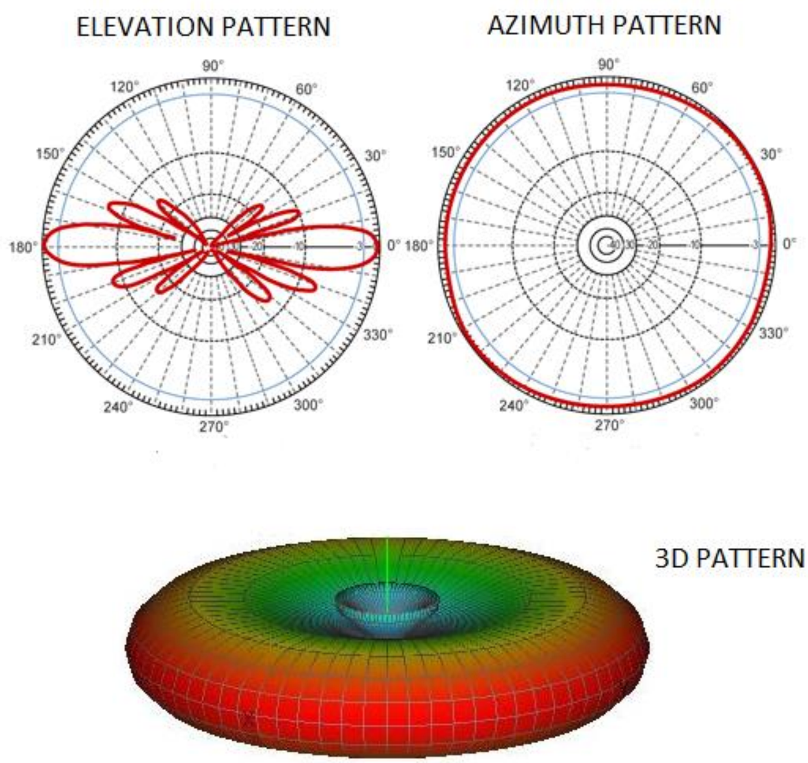


Figure B-3: Radiation Pattern of Network Transmitters Antennas

To enhance the vertical resolution of the antenna’s radiation pattern, an option of placing reciprocating antennas at a circular displacement angle of approximately 12 degrees would give greater vertical resolution and coverage that would be necessary for vertical measurements. To accomplish this would require more hardware components, but would give uniformity and would enhance the location tracking using multilateration by enhancing the distance measurements from the Path Loss Model equation. Any enhancement would lead to further accuracy in beacon location tracking.

Engineering Calculations

The signal strength is directly affected by the distance separated between the receiver and the transmitter. The resultant value in dBm is negative because the open source code is receiving a signal that is approximately equal to 1/distance^2. When converting into a logarithmic scale these values will be negative because the equations use the logarithm of fractions. Some of the common signal strength equations are listed below:

$$PL = P_{Tx_{dBm}} - P_{Rx_{dBm}} = PL_0 + 10\gamma \log_{10} \frac{d}{d_0} + X_g,$$

$$FSPL = (\frac{4\pi d}{\lambda})^2$$

$$FSPL = 20log_{10}(d) + 20log_{10}(f) + C$$

$$\log(d) = ((9245000cm - (20 * \log(GHz)) + \frac{dBm}{20})$$

The above calculations will be useful when manipulating the open-source code to calculate the signal strength of each desired device. Utilizing the Path Loss Model, gives an approximate dBm that is then related to distance. The benefit of using a fixed grid for initial testing will be to correspond the actual location to the location obtained using multilateration. Having the opportunity to correct for disturbances and interpolate the locations based off using the real location will enhance the capability of producing a multilateration algorithm that is effective in compensating for noise in signals and outside disturbances.

Hardware Block Diagram

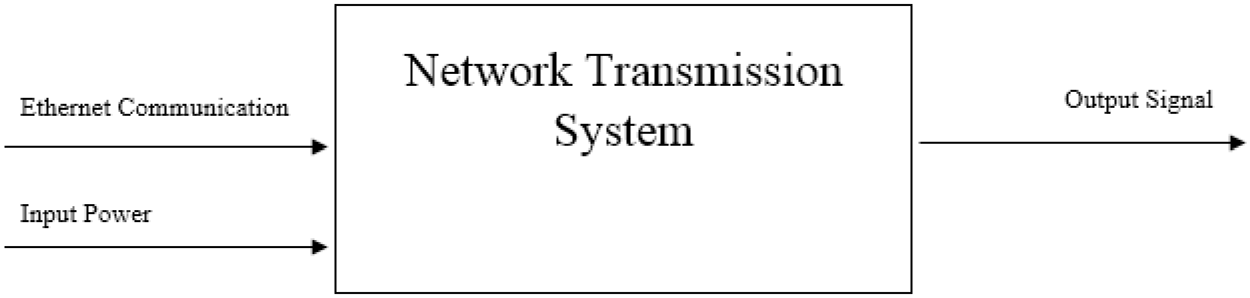


Figure B-4: Level-1 Diagram of the Network Transmitters

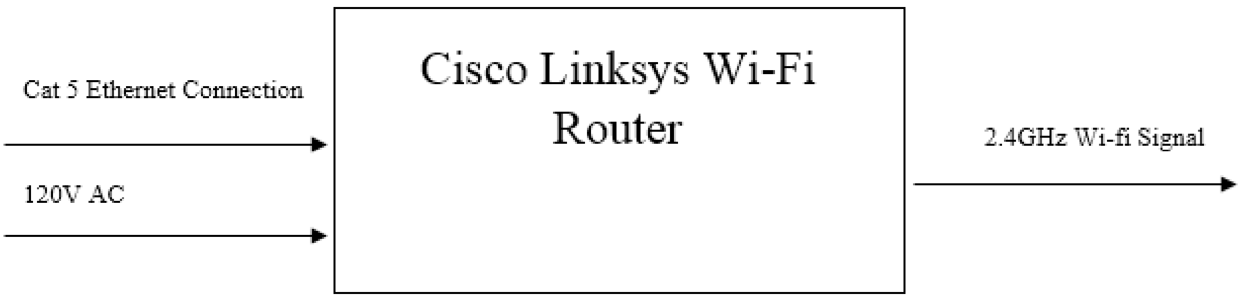


Figure B-5: Level-2 Diagram of the Network Transmitters

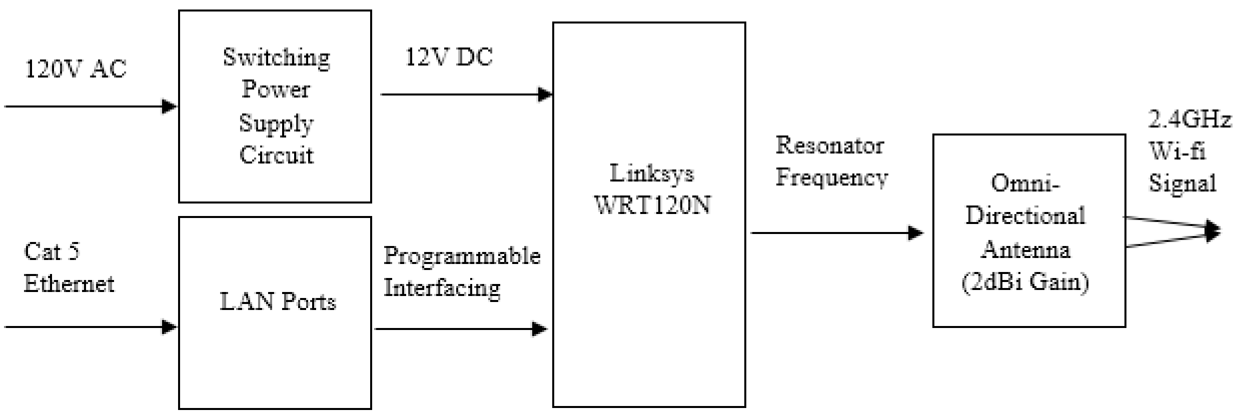


Figure B-6: Level-3 Diagram of the Network Transmitters

Hardware Functional Requirement Table

Module	**Switching Power Supply Circuit**
Inputs	120V AC
Outputs	12V DC
Functionality	Using a switching circuit, this system uses duty cycles to transform the voltage from a standard 120V signal to a steady state value of 12 V DC.

Table B-1: Switching Power Supply Circuit

Module	**LAN Ports**
Inputs	Ethernet Connectivity
Outputs	Network transmitter Configuration
Functionality	Allows interfacing to the Linksys Cisco router to configure identifiable SSID tags and to set up the overall network for use.

Table B-2: LAN Ports

Module	**Linksys WRT120N Wi-Fi Router**
Inputs	12V DC; Programmable Interfacing
Outputs	Resonator Frequency
Functionality	Once the network transmitter is powered on and configured, the use of internet capability is not necessary within the network transmitter's operation. The network transmitter’s main use is the 2.4GHz frequency at an identifiable SSID tag.

Table B-3: Linksys WRT120N Wi-Fi Router

Module	**Omni-Directional Antennas**
Inputs	Network transmitter's resonator signal
Outputs	2.4GHz Wi-Fi Signal
Functionality	Taking the electrical signals from the resonator and the embedded circuits in the network transmitter the antenna will then send an omni-directional wave at a 2.4GHz frequency with a gain of 2dBi.

Table B-4: Omni-Directional Antennas

C. Signal Processing. (TCD, DCB, & AJC)

Description

Theory of Operation

Given the signal strength information collected from output of the beacon, the data will then need to be compressed and processed in such a way that the location computations while be as fast and accurate as possible. By implementing zone-based techniques, the algorithm can account for the error caused by inaccurate data points and increase the speed at which the system locates the beacon. To determine the location of the beacon, data from multiple receivers will be pulled together and processed to provide a single more accurate location. To do this, a single receiver (Mobile Application user) will view signal strength information from the beacon. Since the location of user will already be known, the location of the beacon can be interpolated using this user location and signal strength information. Using the processor embedded in the mobile user's device, the location of the ball can be determined. Given the determined locations of the beacon from multiple receivers, this data can be pooled together to give a single, more accurate beacon location. The location data information will be sent to a central computer, which will further process the data. To process this data quickly and accurately, users will be lumped together in groups called "zones." These zones will contain users with similar known locations and will vastly reduce the computational power needed to determine the beacon location.

Having the ability to interface between the mobile application and the MATLAB code is critical for this system to be successful and to be applicable for use. A seamless integration of an appropriate server will allow for improved processing time, enhanced data capability, and greater efficiency of communication between each interface being used. The most practical application of a web server to be integrated with this system is Amazon Web Server S3 (AWS-S3). AWS-S3 provides the capability of harnessing the data from the mobile application and then MATLAB can read in the stored data and perform linked processing of the data to be exported back to AWS-S3. When specifying the location of the data, the full path to the files must be used through an internationalized resource identifier of the form; s3://bucketname/path_to_file for example. The most common way to access AWS-S3 from MATLAB is using “buckets” as containers to store objects in Amazon S3. To implement a specific file or image from AWS-S3 to MATLAB the follow code will select the data from the file name:

```
setenv('AWS_ACCESS_KEY_ID', 'YOUR_AWS_ACCESS_KEY_ID');
setenv('AWS_SECRET_ACCESS_KEY', 'YOUR_AWS_SECRET_ACCESS_KEY');
setenv('AWS_REGION', 'us-east-1');

ds = imageDatastore('s3://mw-s3-datastore-tests-us/image_datastore/jpegfiles', ...
  'IncludeSubfolders', true, 'LabelSource', 'foldernames');
img = ds.readimage(1);
imshow(img)
```

The AWS-S3 allows REST and SOAP interfaces designed to work with any internet development toolkit. In the system this project seeks to implement, the android platform is where the mobile application will be located and AWS-S3 provides this capability.

Engineering Calculation

Locating an object using RSSI (Received Signal Strength Indication) multilateration is done in multiple steps. First, by understanding a point-to-point connection between a receiver and the beacon. The beacon is an RF transmitter producing a high frequency signal. That transmitted signal is received from the mobile device. While the phone is receiving the transmitted signal, the open source code that handles breaking down the signal using the Path Loss Model, will produce a distance measurement predicated on the dBm of the signal or the signal's strength. Once the correlation between the distance of the receiver and the beacon is confirmed, the point-to-point connection of the receiver and beacon is produced with the receiver being the center and the beacon being a singular point on a sphere. The distance between the receiver and beacon is the radius of the conceptual sphere in space. Next, by perpetually adding more receivers to the system, conceptual spheres, all varying in radii fixated on the beacon, are produced. Using the equations on the next page as the idealized expressions, the spheres will intersect in one centralized, 3-dimensional point, which is the location of the beacon.

To determine the location of a single receiver relative to an X-Y-Z grid imposed over a field, multilateration will be used. Given multiple network transmitters, outputting different SSID signals from fixed known locations, the system can determine the location of a single receiver. Explicitly, by mapping the signal strengths of the network transmitters onto the X-Y-Z grid and then comparing those with the signal strength seen by the receiver the location is produced. With at least four network transmitters all extraneous solutions can be eliminated and a receiver location can be determined.

To determine the location of the beacon relative to an array of receivers a similar logic is used. Given an array of receivers each with a known location, each seeing a signal strength from the beacon, the open source code embedded in the mobile application can determine the location from the radiation pattern of the beacon and fitting that pattern onto the X-Y-Z grid such that it matches the signal strengths seen by the receivers. The created spheres will have radii below, where x_n , y_n and z_n are the know locations of the receivers 1 through n:

$$d_1{}^2 = (x - x_1)^2 + (y - y_1)^2 (z - z_1)^2$$
$$d_2{}^2 = (x - x_2)^2 + (y - y_2)^2 (z - z_2)^2$$
$$d_n{}^2 = (x - x_n)^2 + (y - y_n)^2 (z - z_n)^2$$

To determine the radii of these spheres, a technique called fingerprinting will be used that will map the radiation pattern of the beacon. By obtaining the signal strength at any given distance, the MATLAB algorithm is able to assign a radius to each receiver by measuring the signal strength. The algorithm then finds the equivalent radii points of each connection, which allows the ability to fixate on one central point, being the location of the beacon or mobile device.

Using the process of fingerprinting the system will be able to determine the radius from the ball to each receiver, but because signals do not propagate through space in an ideal manner, the system will need to recalculate these radii for every location used in this system. To do this open source code embedded in the mobile application will test the received signal strength between two fixed devices with known distances apart. Once that information is known the open source code embedded in the mobile application can solve the following equation for η.

$$RSSI=-(10\eta\log(d)+A)$$

With η being known the MATLAB algorithm can then solve the equation for the unknown d to determine the radius from beacon to a given receiver. Since environmental factors can heavily change a signal's propagation characteristics this process will allow the system to associate the received signal strength with a device radius.

Because not all environmental factors can be accounted for, as well as the possibility of devices recording incorrect values, the measurements will have some inherent errors. One such error is the possibility of multiple possible beacon locations appearing. This error can oftentimes be easily mitigated as these "phantom" beacon locations may either appear outside of the play area which immediately disqualifies them as accurate. The phantom locations may also be far enough away from the actual location of the beacon that the human eye can easily discern that the location is inaccurate. In figure C-1, located on the next page, the concept of the red zone that occurs when a single equivalent point does not occur is shown. In this figure, the radii of the varying receiver to beacon connections do not intersect. This error is due to a variety of issues with inconsistencies in signal strength to signal noise. The concept of creating a zone of potential location for the beacon will need to be implemented in the algorithm so that when error is present the beacon's location can be inferred to be located in the zone.

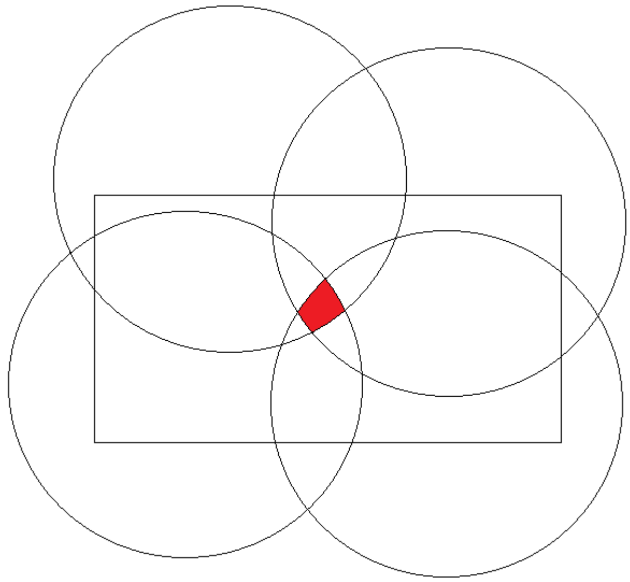


Figure C-1: Zoning Approximation With Realized Multilateration

Because the zone is undesirable compared to a fixed point when resolution is a concern. Increasing the number of receivers creates more spheres into the equation. When more spheres are accounted for in terms of the zone, eventually to zone will shrink to a point that is within the necessary resolution guidelines. Currently the assumption of increasing the number of receiver nodes to infinity will result in a fixed point. Obviously, this is unobtainable, but the resolution that would present itself from specific number of receivers is useful information even outside of the context of this project. Another issue that arises with the concept of zoning is that some spheres may exists outside of the zone to a point where including the sphere in the zoning approximation would decrease accuracy. Therefore, developing a method to discern outlying data from the spheres that increase resolution is a major concern to increase resolution.

Hardware Block Diagram

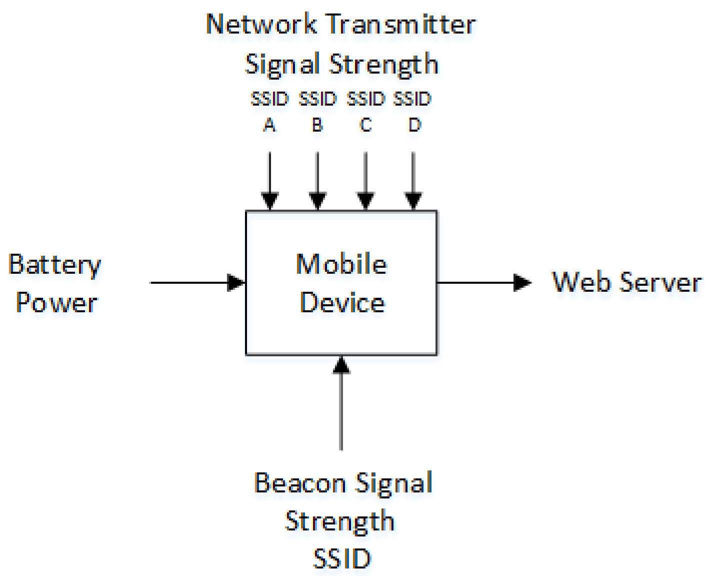


Figure C-2: Mobile Device Hardware Block Diagram

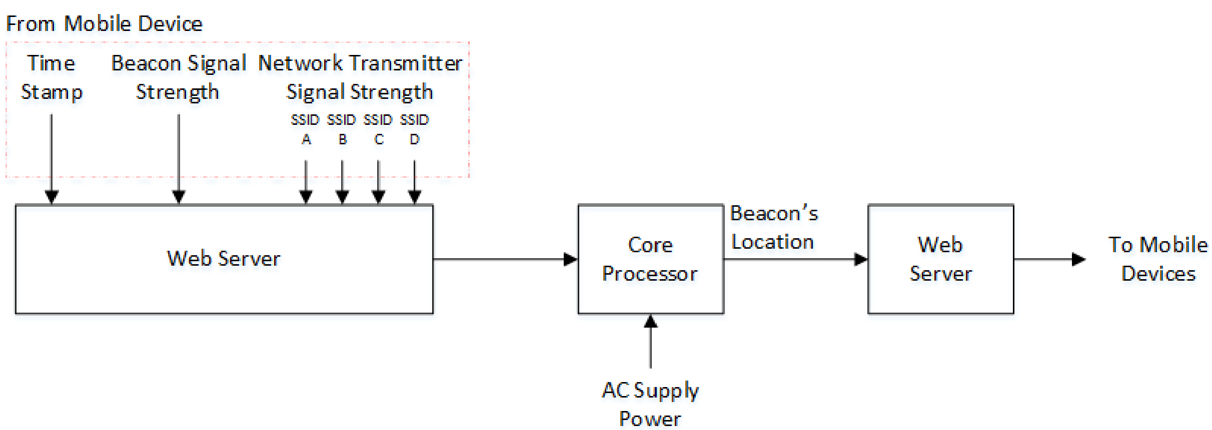


Figure C-3: Data Transfer Block Diagram

Hardware FR Table

Module	**Mobile Device**
Inputs	Cellphone Battery Power, Network Transmitters, and Beacon Signal Strengths
Outputs	4 Network Transmitter Signal Strengths, Beacon Signal Strength, and Time Stamp
Functionality	The mobile device outputs the needed variables to the web server. This device will simply measure the signal strengths and output them with their corresponding time stamp.

Table C-1: Mobile Device

Module	**Web Server**
Inputs	4 Network Transmitter Signal Strengths, Beacon Signal Strength, and Time Stamp
Outputs	4 Network Transmitter Signal Strengths, Beacon Signal Strength, and Time Stamp
Functionality	Provided by a third part the web server will connect the core processor to the data needed for the multilateration calculations. It will be used to transfer information between the core processor and mobile devices.

Table C-2: Web Server

Module	**Core Processor**
Inputs	4 Network Transmitter Signal Strengths, Beacon Signal Strength, and Time Stamp, 120 VAC Supply Power
Outputs	Beacon's Location and Time Stamp
Functionality	At a hardware level, the core processor is a desktop computer with software that will be used to conduct multilateration algorithms.

Table C-3: Core Processor, Hardware

Software Block Diagram

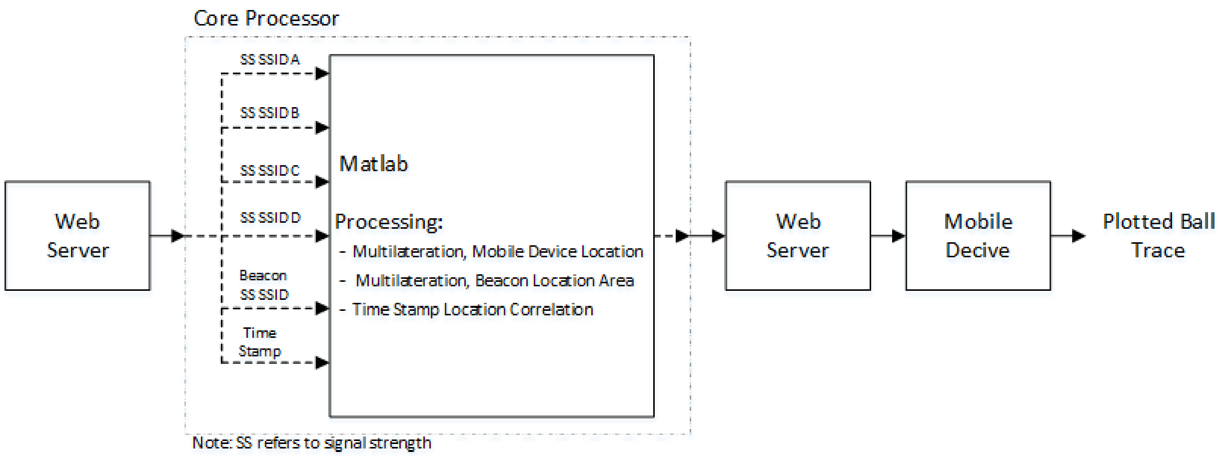


Figure C-4: Software Block Diagram

Software FR diagram

Module	**Core Processor**
Inputs	4 Network Transmitter Signal Strengths, Beacon Signal Strength, and Time Stamp
Outputs	Mobile Device Location, Beacon Location Area, and Time Stamp
Functionality	The core processor receives the data from a cloud based web server that is capable of interfacing with both Android and Matlab. It then uses the received variables to conduct the multilateration calculations.

Table C-4: Core Processor, Software

Module	**Amazon Web Server - S3**
Inputs	Data from Receiver
Outputs	Data to Beacon locator
Functionality	This module will facilitate the transfer of data from the receiver to the central processor. Implementing AWS-S3 to interface with mobile devices and MATLAB algorithms.

Table C-5: Amazon Web Server - S3

D. Software Design

Description

Theory of Operation

The heart of this project is the mobile phone application. With the availability of a mobile device application readily downloadable to everyone at a specific sporting event for example, the system can use the large population of mobile phone users to it's and the game's, advantage.

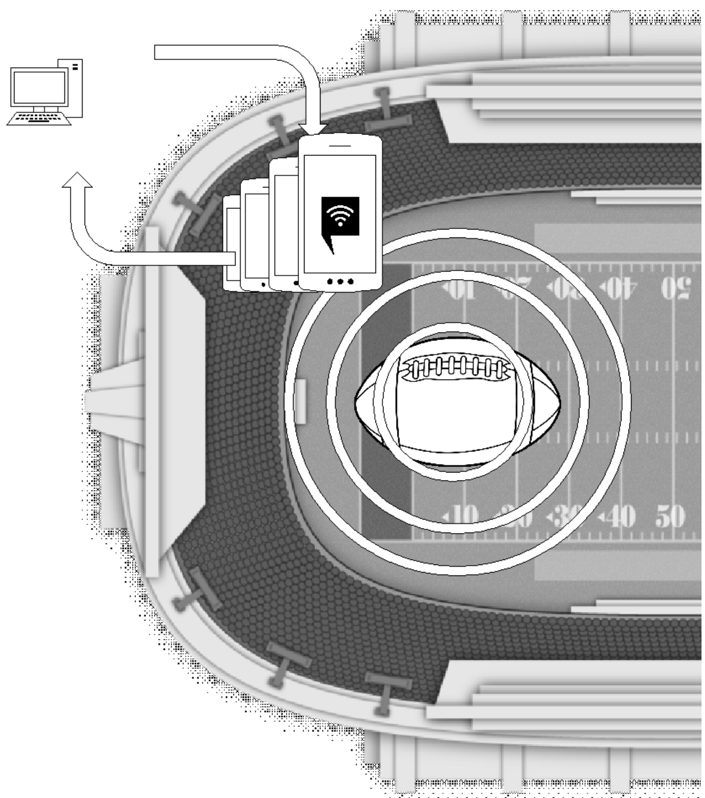


Figure D-1: Level 0 Diagram of System

In the diagram, Figure D-1, shows the basics of what is required to be implemented. The project's application will be implemented in a football stadium, like the one shown, where the football is a beacon of Wi-Fi signal. User's phones, through the mobile application, will read the signal strength of the Wi-Fi beacon in the ball. The phone will then send the information gathered to a central processor, like a web server, where the data will be processed. After processing, the data will be sent back to the users' phones thus the location of the Wi-Fi beacon within the ball will be identified.

Software Block Diagram

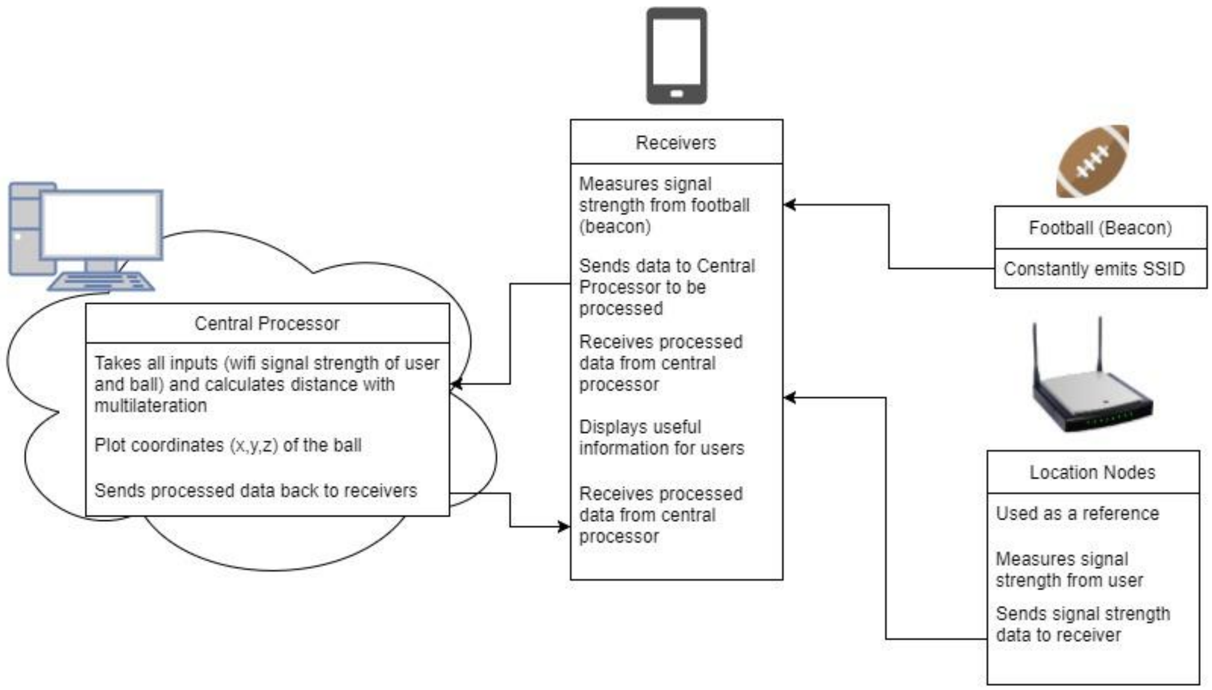


Figure D-2: Level 1 Block Diagram of Software

In the figure above, Figure D-2, shows in more detail the software application. First, after the user has the mobile application in their device. Their device will be connected to a network of locator nodes consisting of at least three nodes – three for triangulation to work. Using their three individual signal strengths to the user, the nodes will be able to triangulate where the user is on the network. This data will be sent to the application for further processing.

When the data has been collected by the application from the locator nodes, at the same time, the mobile application will be reading the signal strength of the ball beacon. This reading gives a measurement in decibel milliwatts where the open source code can convert the measurement into an approximate distance calculation using the Path Loss Model. Once these two pieces of information, the user's location in the stadium and the signal strength of the beacon, are collected, the data will be transferred to a central processor for further analysis.

The data processor, a web server or cloud backend, will be processing all the participants' user data to determine the location of the ball on the field. Based upon the user's location in the stadium, their signal strength reading from the beacon, then comparing each reading to another participant's, the system can narrow down the exact location of the ball and display it on the users' application via a graphical interface.

Code

```
class User
{
    public:
        User();
        userLocation;                   //feet
        float signalStrengthFromBall;//dBm

    protected:

    private:
};
```

Figure D-3: LocatorNodes Class and Data Members

Above in Figure D-3, is the LocatorNodes class with its respective data members. First being the network IP that the user's' application will need to connect. In a real-world application, each stadium would have a unique static IP so it will remain the same and the application will always be able to discover it. Next is the nodes' coordinates in relation to one another, nodeCoordinates. Without these coordinates as reference, the locations of the users could not be determined. Finally, the signalStrengthToUser is the signal strength the nodes see in relation to the user. Again, using triangulation, the nodal network will determine, based off Wi-Fi signal strength, where the location is of the user and assigns that location to the user object.

```
class ballBeacon
{
    public:
        ballBeacon();
        float ballLocation;            //feet
        const int SSID;

    protected:

    private:
};
```

Figure D-4: ballBeacon Class and Data Members

Figure D-4 shows the last class for the beacon inside the ball, ballBeacon. The data member, ballLocation, will not be assigned until after:

1. User location has been determined
2. Wi-Fi signal strength readings are sent from each user to the central processor
3. Data from each user's readings has been processed

Once these have been determined, the location of the ball has also been found, the system can then use the ball's location to emulate, on the mobile application, a graphic for the user to then read. This graphic display should be synonymous to the other user interfaces across the playing field.

```java
private void performWiFiScan() {
    List<ScanResult> scanResults = Collections.emptyList();
    WifiInfo wifiInfo = null;
    List<WifiConfiguration> configuredNetworks = null;
    try {
        if (!wifiManager.isWifiEnabled()) {
            wifiManager.setWifiEnabled(true);
        }
        if (wifiManager.startScan()) {
            scanResults = wifiManager.getScanResults();
        }
        wifiInfo = wifiManager.getConnectionInfo();
        configuredNetworks = wifiManager.getConfiguredNetworks();
    } catch (Exception e) {
        // critical error: set to no results and do not die
    }
    cache.add(scanResults);
    wiFiData = transformer.transformToWiFiData(cache.getScanResults(), wifiInfo, configuredNetworks);
}

public WiFiData getWiFiData() { return wiFiData; }
```

Figure D-5: performWifiScan Function and getWifiData

Above is Figure D-5, which shows the code for the two main functions for performing the Wi-Fi signal strength reading that is so pertinent to the project. When the function is called, first it makes sure the Wi-Fi functionality of the phone is turned on. Then, from the wifiManager class, if getScan has begun, the results are saved, which includes the Wi-Fi signal strength. If there is a Wi-Fi signal to be found, finally, the Wi-Fi information, such as its SSID is saved. If the try statement fails, such as there not being a Wi-Fi signal to detect, then an exception is thrown. The results of the scan are saved and cached. The other function, getWifiData, is a public function that simply gets the data to wherever it is called.

```java
public long getTimeStamp(){
    return System.currentTimeMillis();
}
public boolean onTouch(View, MotionEvent event) {
    long time = 0;
    if (event.getAction() == MotionEvent.ACTION_DOWN) {
        // grab tim eon press
        time = getTimeStamp();
    } else if (event.getAction() == MotionEvent.ACTION_UP) {
        // grab tim eon release
        time = getTimeStamp();
    }
    return false;
}
```

Figure D-6: getTimeStamp Function

In Figure D-6, the piece of code shown is the time stamping function called getTimeStamp. This function is important for isolating the important times of game, thus reducing the amount of unnecessary data when the movement of the ball is not critical yet. For testing, there will be a button on the application that will act as a significant moment in the game that should be recorded, such as the moment before and after an out-of-bounds or whistle blow. Defined firstly is the function getTimeStamp that, like stated before, gets a timestamp in milliseconds. This function is called when onToch, a function that is called when a touch gesture occurs on an object on the application screen such as a button, is called as well. Then, when the button is released, the getTimeStamp function is called again to fetch another timestamp. This means there was a time interval created with the button-hold that is also related to an interval of Wi-Fi signal strength measurements taken at the same interval of time. This is how pertinent moments of the game can be isolated for location measurement.

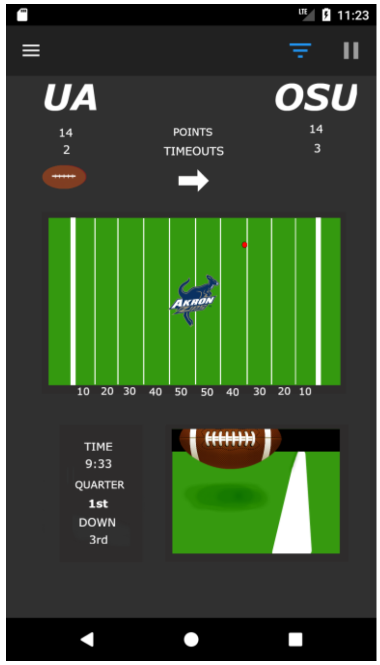


Figure D-7: Android Application Screenshot

Figure D-7 depicts the vision of the final application screen. The application will cater to both coaches, who want statistics of game analysis and spectators, who are interesting in engaging more with the game. The screen shows up-to-date current stats like score, possession, ball direction, game time, quarter and down, which is information that spectators like to have. The novelty part of the project is the additional two screen on the display. The top screen, depicting a 2-dimensional football field, shows the x and y-plane. The beacon, or football, is represented by a red dot. The second screen, just below, represents the z-plane of the beacon. This screen is important because when it comes to the rules of football, the football is the point that is spotted for the call of a touchdown or first-down, not the player's body. So, even though the player is behind the line of the end zone, if the ball is anywhere over the line, it counts as a score. Thus, only having the x and y-plane would not be enough information to satisfy the need of the important call a referee or enthusiastic fan might make.

```
recieverLocation = xycoordinate;
ballSignalStrength = dBW;
timeSample = arrayTime[];

int dataSend(a,b,c){
        JSONtransform(a,b,c);
        dataSentSuccess = JSONsend();
        if (dataSentSuccess){
                return 1;
        }
        else {return 0;}
}

void dataReceive(){
        results = null;
        results = getJSONMulitlaterationResults();
        try {
                if results = (null) {throw exception}
                else {
                        plotXYZonGUI();
                        updateGUI();
                }
        }
        catch (exception) {
        print "Error occured in calculation"
        }
}
```

Figure D-8: Pseudo Code for Data Transferring

When using multilateration, a more complex mathematical operation, it would greatly slow the response time of a mobile phone operation system. Instead, implementing MATLAB into the system by offloading MATLAB onto a cloud and then sending the data to be calculated with a data transfer would alleviate the pain on the mobile phone. More research needs to be done to implement this; however, it is possible with an already available API provided by

Amazon Cloud systems. Above in Figure D-8, the process for the application is shown. By turning the data gathered by the application on the mobile phone into JSON strings instead, the data transfer is much easier because it can be group all in one string array and sent with one data transfer. Then on the other side, the data is parsed and the calculations can be done. Again, the data can be sent back via JSON transformation and parsed by the application for further use.

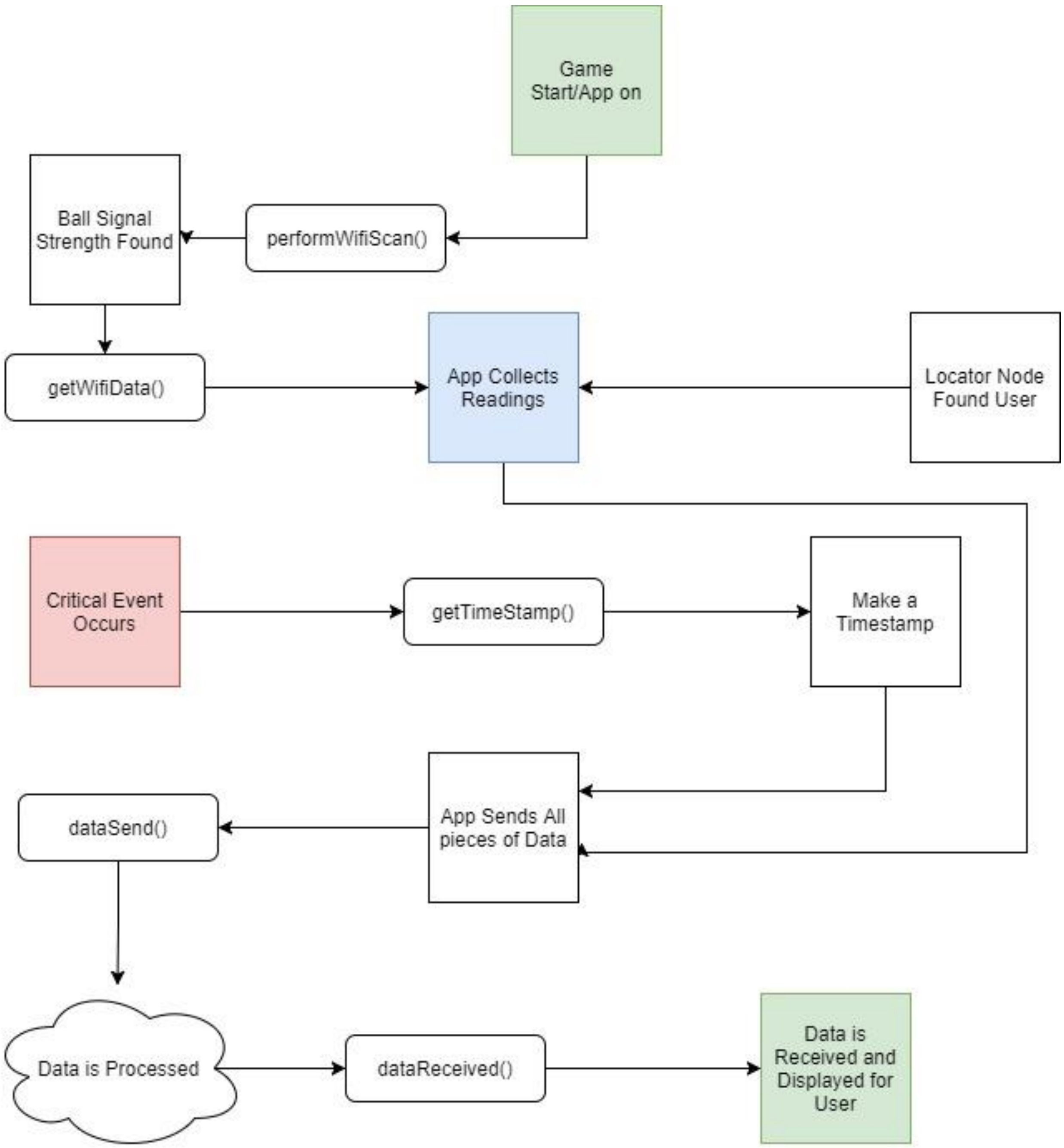


Figure D-9: Software Event Flowchart

Having the application constantly measuring Wi-Fi signal strength and sending data back and forth to the central processor would not be efficient for the speed of calculations for up-to-date information users would like, and the amount of battery life and memory that would be used by the user’s mobile phone would not be ideal. Above in Figure D-9 is a software flowchart that describes the series of events and functions that are called to react to said events. The top box in green is where the events begin. With the application on and running on the user’s device, the application will scan for the beacon using the function performWifiScan. Once the ball is detected SSID and signal strength are saved using the function getWifiData. At the same time, the user’s location will be recorded via the locator nodes and both pieces of information will be stored on the user’s device. This event is in blue indicating that the application is waiting for an event to happen. When an event happens, as indicated by the red box, a timestamp will be created with the sample being when the event took place. Next, all three of those pieces, the user’s location, the ball’s signal strength, and the timestamp, are sent to the central processor when the pseudo code function dataSend() is called. After the calculations and data processing is complete, the pseudo code function dataReceived() is called to interpret the data sent back by the central processor and then display it for the user in a useful way.

Budget and Parts List

Item	Qty	Name	Description	Cost
1	3	Linksys Wireless-N Home Router	Model No. WRT120N; This Router allows configurable SSID needed for signal detection and transmits an omni-directional signal needed for our network transmitter application.https://smarttechsave.com/products/linksys-wrt120n-refurbished-wireless-router	$224.10
2	1	Husky 100 ft. 16/2 Outdoor Extension Cord	Needed to demonstrate network transmitters operations in open areas	$ 18.97
3	4	Prime Wire 25-Foot 16/3 SJTW Medium Duty Extension Cord, Orange	Needed to demonstrate network transmitters operations in open areas	$ 51.96
4	1	GE 6 Outlet Power Strip	Needed to connect network transmitters for powering	$ 5.29
5	1	1-1/2 in. Furniture Grade PVC 3-Way Elbow in White (4-Pack)	Needed for construction of grid. https://www.homedepot.com/p/Formufit-1-1-2-in-Furniture-Grade-PVC-3-Way-Elbow-in-White-4-Pack-F1123WE-WH-4/205749500?MERCH=REC-_-NavPLPHorizontal1_rr-_-NA-_-205749500-_-N	$ 11.15
6	8	Charlotte Pipe 1-1/2-in x 10-ft 330-PSI Sch 40 Solidcore PVC DWV Pipe	Needed for construction of grid. https://www.lowes.com/pd/Charlotte-Pipe-1-1-2-in-x-10-ft-330-PSI-Sch-40-Solidcore-PVC-DWV-Pipe/3133037	$ 39.68
7	2	Red Heart Super Saver Yarn, BLACK	Used for interpolation of location of beacon. https://www.walmart.com/ip/Red-Heart-Super-Saver-Yarn-BLACK/19478700?wmlspartner=wlpa&adid=22222222227015429596&wl0=&wl1=g&wl2=c&wl3=40940315792&wl4=pla-78876755912&wl5=9015401&wl6=&wl7=&wl8=&wl9=pla&wl10=8175035&wl11=online&wl12=19478700&wl13=&veh=sem	$ 11.68
8	1	RF Transmitter	IC RF TXRX+MCU BLUETOOTH 48VFQFN	$ 4.62
9	1	RF Transmitter	Microchip's WINC1500	$ 11.82
				$ 379.27

Project Schedule

Gantt Chart 2017:

Task Name	Duration	Start	Finish	Resource Names
SDP1 fall2017				
Project Design				
Preliminary Design Report				
Problem Statement	21 days	Tue 8/29/17	Mon 9/18/17	
Need	14 days	Tue 8/29/17	Mon 9/11/17	TCD
Objective	14 days	Tue 8/29/17	Mon 9/11/17	TCD
Background	14 days	Tue 8/29/17	Mon 9/11/17	TCD
Marketing Requirements	14 days	Tue 8/29/17	Mon 9/11/17	DCB
Objective Tree	14 days	Tue 8/29/17	Mon 9/11/17	DCB
Preliminary Design Gantt Chart	14 days	Tue 9/5/17	Mon 9/18/17	DCB
Block Diagrams Level 0, 1, ... w/ FR tables	**14 days**	Tue 9/5/17	Mon 9/18/17	
Hardware modules (identify designer)	14 days	Tue 9/5/17	Mon 9/18/17	AJC
Software modules (identify designer)	14 days	Tue 9/5/17	Mon 9/18/17	BMS
Preliminary Design Presentation 9:55am	1 day	Tue 9/19/17	Tue 9/19/17	TCD
Midterm Report	**28 days**	**Tue 9/19/17**	**Mon 10/16/17**	
Design Requirements Specification	7 days	Tue 9/19/17	Mon 9/25/17	DCB
Midterm Design Gantt Chart	28 days	Tue 9/19/17	Mon 10/16/17	DCB
Design Calculations	**28 days**	**Tue 9/19/17**	**Mon 10/16/17**	
Electrical Calculations	**28 days**	**Tue 9/19/17**	**Mon 10/16/17**	
Beacon	28 days	Tue 9/19/17	Mon 10/16/17	DCB
Network Transmitter	28 days	Tue 9/19/17	Mon 10/16/17	TCD
Core Processor	28 days	Tue 9/19/17	Mon 10/16/17	AJC
Mobile Application	28 days	Tue 9/19/17	Mon 10/16/17	BMS
Mechanical Calculations	**28 days**	**Tue 9/19/17**	**Mon 10/16/17**	
Structual Considerations	28 days	Tue 9/19/17	Mon 10/16/17	DCB
System Dynamics	28 days	Tue 9/19/17	Mon 10/16/17	TCD
Block Diagrams Level 2 w/ FR tables & ToO	**7 days**	**Tue 9/19/17**	**Mon 9/25/17**	
Hardware modules (identify designer)	7 days	Tue 9/19/17	Mon 9/25/17	DCB
Software modules (identify designer)	7 days	Tue 9/19/17	Mon 9/25/17	BMS
Block Diagrams Level 3 w/ FR tables & ToO	**7 days**	**Tue 9/19/17**	**Mon 9/25/17**	
Hardware modules (identify designer)	7 days	Tue 9/26/17	Mon 10/2/17	TCD
Software modules (identify designer)	7 days	Tue 9/26/17	Mon 10/2/17	BMS
Midterm Design Presentations 9:55-11:35am Part 2	1 day	Tue 10/24/1	Tue 10/24/17	TCD
Project Poster	37 days	Tue 10/31/1	Wed 12/6/17	DCB
Final Design Report	**42 days**	**Tue 10/17/1**	**Mon 11/27/17**	
Abstract	42 days	Tue 10/17/1	Mon 11/27/17	TCD
Software Design	**42 days**	**Tue 10/17/1**	**Mon 11/27/17**	**BMS**
Modules 1...n	**42 days**	**Tue 10/17/1**	**Mon 11/27/17**	
Psuedo Code	42 days	Tue 10/17/1	Mon 11/27/17	BMS
Hardware Design	**42 days**	**Tue 10/17/1**	**Mon 11/27/17**	
Modules 1...n	**42 days**	**Tue 10/17/1**	**Mon 11/27/17**	
Simulations	42 days	Tue 10/17/1	Mon 11/27/17	DCB
Schematics	42 days	Tue 10/17/1	Mon 11/27/17	DCB
Parts Request Form	42 days	Tue 10/17/1	Mon 11/27/17	TCD
Budget (Estimated)	42 days	Tue 10/17/1	Mon 11/27/17	TCD
Implementation Gantt Chart	42 days	Tue 10/17/1	Mon 11/27/17	DCB
Conclusions and Recommendations	42 days	Tue 10/17/1	Mon 11/27/17	DCB
Final Design Presentations 9:55-11:35am Part 1	1 day	Tue 11/28/1	Tue 11/28/17	TCD
Final Report Due	1 day	Fri 12/1/17	Fri 12/1/17	DCB

Gantt Chart 2018:

Task Name	Duration	Start	Finish	Resource Names
SDPII Implementation 2017	105 days	Tue 1/16/18	Mon 4/30/18	
Revise Gantt Chart	14 days	Tue 1/16/18	Mon 1/29/18	DCB
Implement Project Design	97 days	Tue 1/16/18	Sun 4/22/18	
Hardware Implementation	56 days	Mon 1/15/18	Sun 3/11/18	
Antenna Construction	21 days	Mon 1/15/18	Sun 2/4/18	DCB
Beacon Breadboard Components	21 days	Mon 1/15/18	Sun 2/4/18	DCB
Beacon PCB Layout	21 days	Mon 1/15/18	Sun 2/4/18	DCB
Network Transmitter Mounts and Grid	7 days	Mon 1/15/18	Sun 1/21/18	TCD
Network Transmitter's Power Distribution	7 days	Mon 1/15/18	Sun 1/21/18	TCD
Network Transmitter's Radiation Mapping	7 days	Mon 1/22/18	Sun 1/28/18	TCD
Core Processor Hardware Setup	1 day	Mon 1/15/18	Mon 1/15/18	DCB
Assemble Hardware	7 days	Mon 2/5/18	Sun 2/11/18	DCB,TCD
Test Hardware	14 days	Mon 2/12/18	Sun 2/25/18	DCB,TCD
Revise Hardware	14 days	Mon 2/26/18	Sun 3/11/18	DCB,TCD
MIDTERM: Demonstrate Hardware	5 days	Mon 2/26/18	Fri 3/2/18	DCB,TCD
SDC & FA Hardware Approval	0 days	Mon 3/12/18	Mon 3/12/18	DCB,TCD

Software Implementation	56 days	Mon 1/15/18	Sun 3/11/18	
Core Processor Programming	28 days	Mon 1/15/18	Sun 2/11/18	AJC,DCB,TCD
Web Server Interfacing	28 days	Mon 1/15/18	Sun 2/11/18	TCD
Mobile Device Programming	28 days	Mon 1/15/18	Sun 2/11/18	BMS
Mobile Device Setup	7 days	Mon 2/12/18	Sun 2/18/18	BMS
Test Software	7 days	Mon 2/19/18	Sun 2/25/18	BMS,TCD
Revise Software	21 days	Mon 2/26/18	Sun 3/18/18	BMS,TCD
MIDTERM: Demonstrate Software	5 days	Mon 3/19/18	Fri 3/23/18	BMS,TCD
SDC & FA Software Approval	0 days	Mon 3/12/18	Mon 3/12/18	BMS,TCD
System Integration	42 days	Mon 3/12/18	Sun 4/22/18	
Assemble Complete System	14 days	Mon 3/12/18	Sun 3/25/18	AJC,BMS,DCB,TCD
Test Complete System	21 days	Mon 3/26/18	Sun 4/15/18	AJC,BMS,DCB,TCD
Revise Complete System	21 days	Mon 3/26/18	Sun 4/15/18	AJC,BMS,DCB,TCD
Demonstration of Complete System	7 days	Mon 4/16/18	Sun 4/22/18	AJC,BMS,DCB,TCD
Develop Final Report	105 days	Tue 1/16/18	Mon 4/30/18	
Write Final Report	98 days	Tue 1/16/18	Mon 4/23/18	AJC,BMS,DCB,TCD
Submit Final Report	0 days	Mon 4/23/18	Mon 4/23/18	AJC,BMS,DCB,TCD
Spring Recess	7 days	Mon 3/26/18	Sun 4/1/18	
Project Demonstration and Presentation	0 days	Mon 4/23/18	Mon 4/23/18	

Conclusion and Recommendations

By using an array of receivers, whose locations will be determined using fixed network transmitters, a beacon can be located in space using the signal strength seen by the receiver. Using fixed network transmitters, the algorithm that interprets user data can determine the location of a receiver using RSSI multilateration, which will interpolate the receiver location using RSSI multilateration as well. A beacon will then output a signal, which will be seen by numerous receivers. RSSI multilateration can be used again to determine the location of the beacon. Because a large array of receivers will be used, techniques to reduce the quantity of data and speed of computation also need to be explored. “Zoning” is one such technique that works by lumping the receivers into groups which will be processed at the same time. The receivers will also be inhomogeneous devices with different specifications. This can cause issues with the received signals and application compatibility from device to device. As such, devices will need to be tested to ensure compatibility with this system. Lightweight beacons are also to be desired. Since the beacon can be implemented in an object like a football, the device should be as lightweight and non-obtrusive as possible while also being able to meet a reasonable operating time for the given application.

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Appendix

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