BLUEWALKER

Beacon Indoor Navigation System

Group 14
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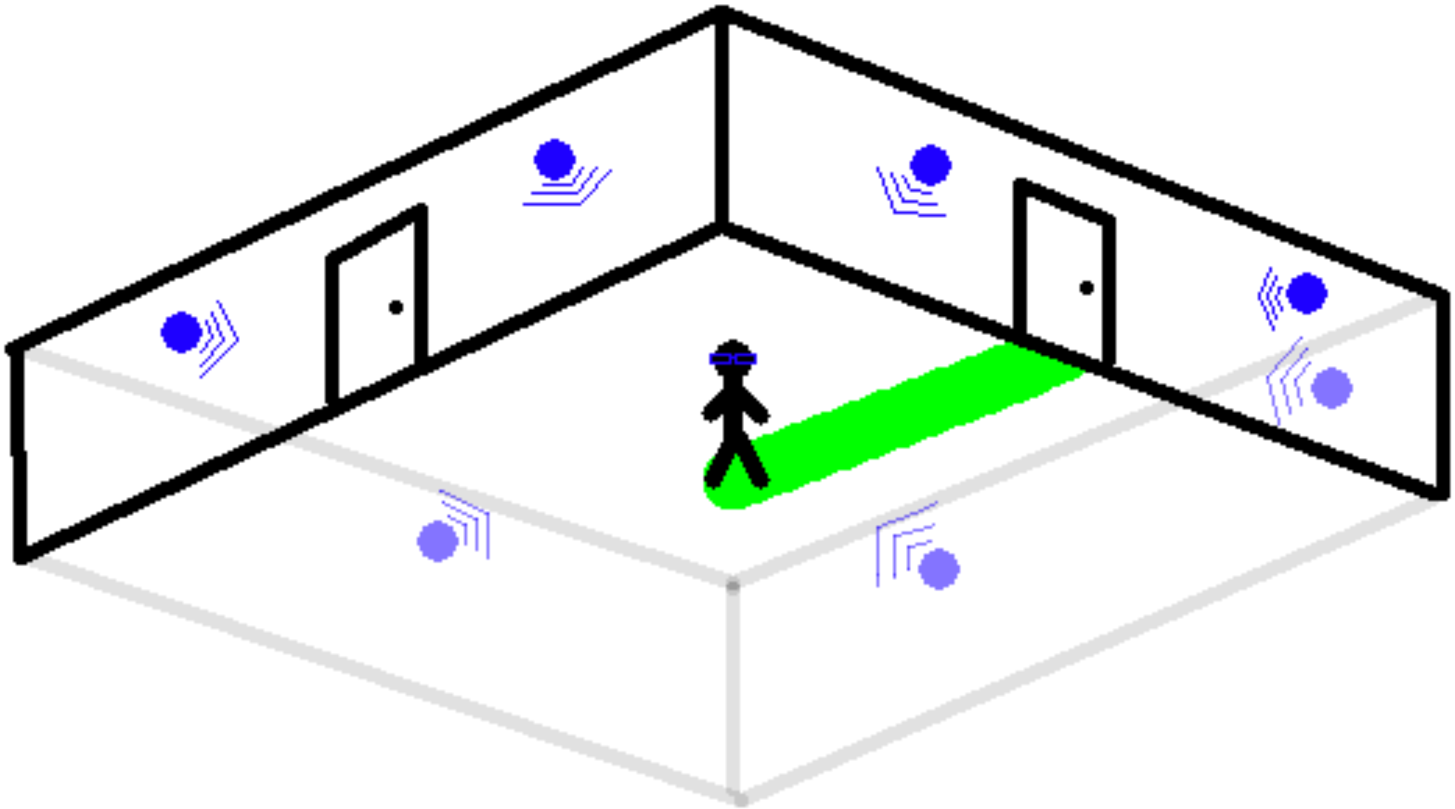
Motivation

- GPS technologies are not effective indoors
- Current indoor accessibility implementations for navigation are limited
- Gain experience working in our respective research fields

Objectives

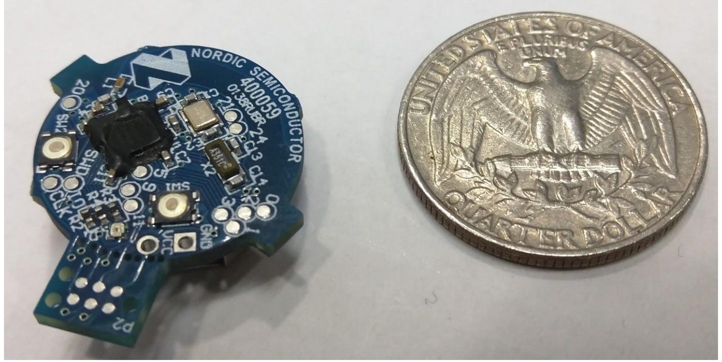
- To create an accurate indoor navigation system with an easy-to-use user interface.
- Develop beacons that utilize the Bluetooth Low Energy specification allowing for low power consumption
- Provide a complete open-source solution in both hardware and software

System Concept



iBeacon

- Uses Bluetooth 4.0
- Developed by Apple
- Signal contains
  - UUID (Universally unique identifier) - 128-bit value
  - Major - 16-bit unsigned integer
  - Minor - 16-bit unsigned integer
  - Calibration RSSI - 16-bit signed integer
- 100ms advertising interval
  - Some manufacturers use 900ms for lower power consumption

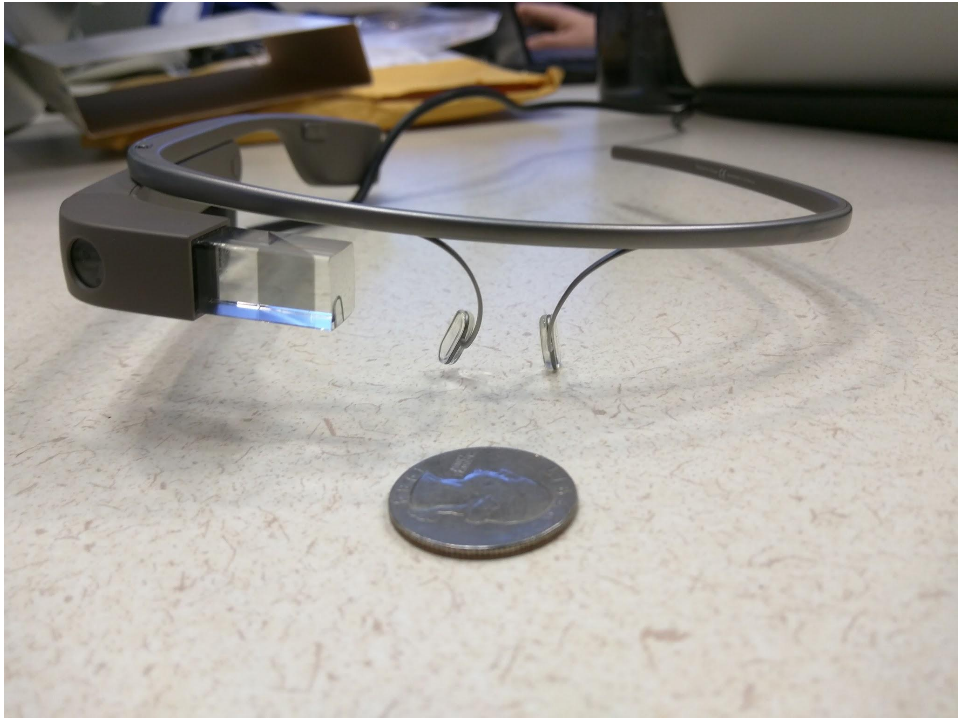


Google Glass

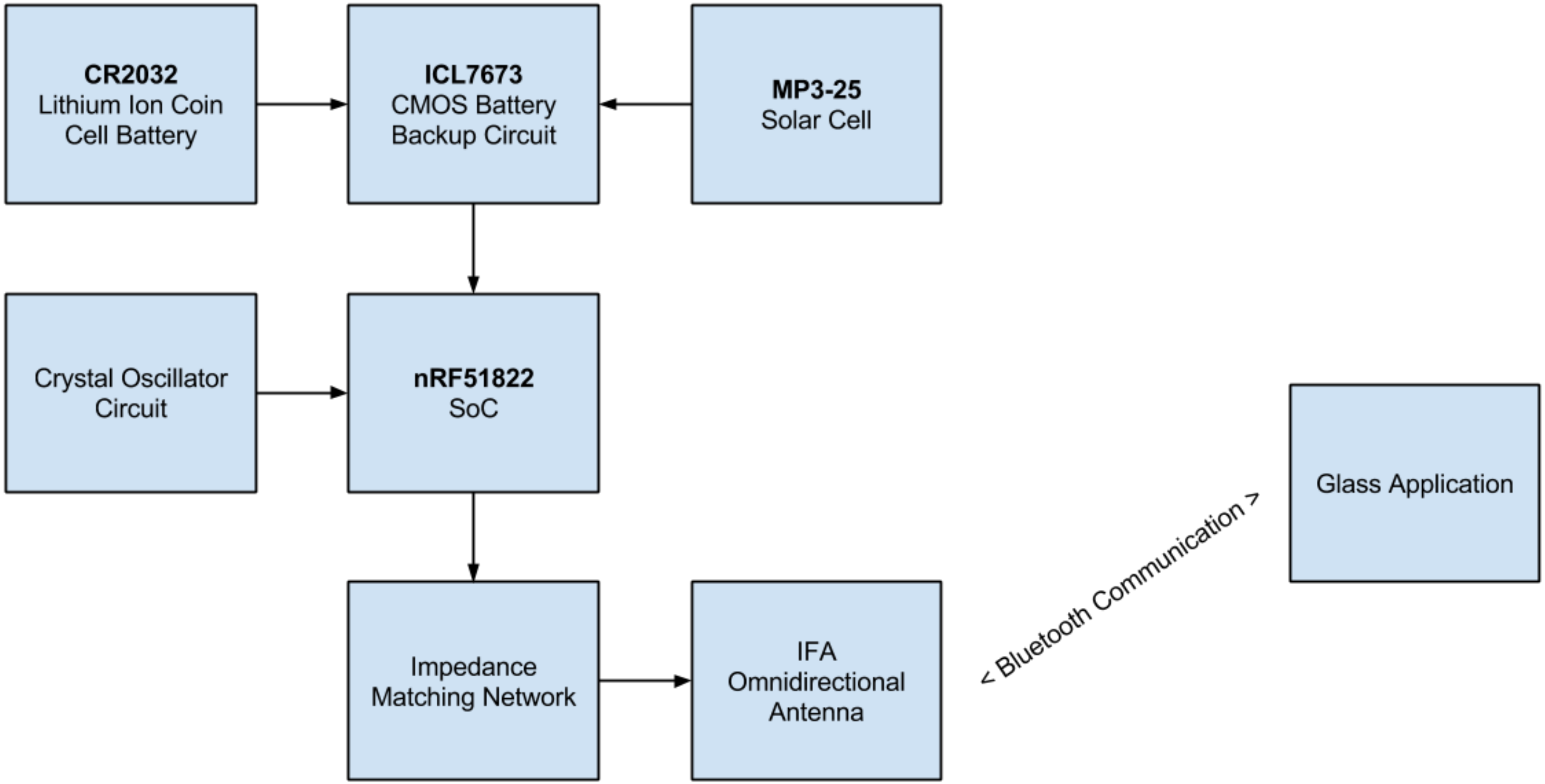
- Allows the user to easily communicate with the device by only using only their voice. (hands-free)

- Allows for easy compatibility with other Android devices.

- Investigate the potential advantages of wearables combined with indoor positioning



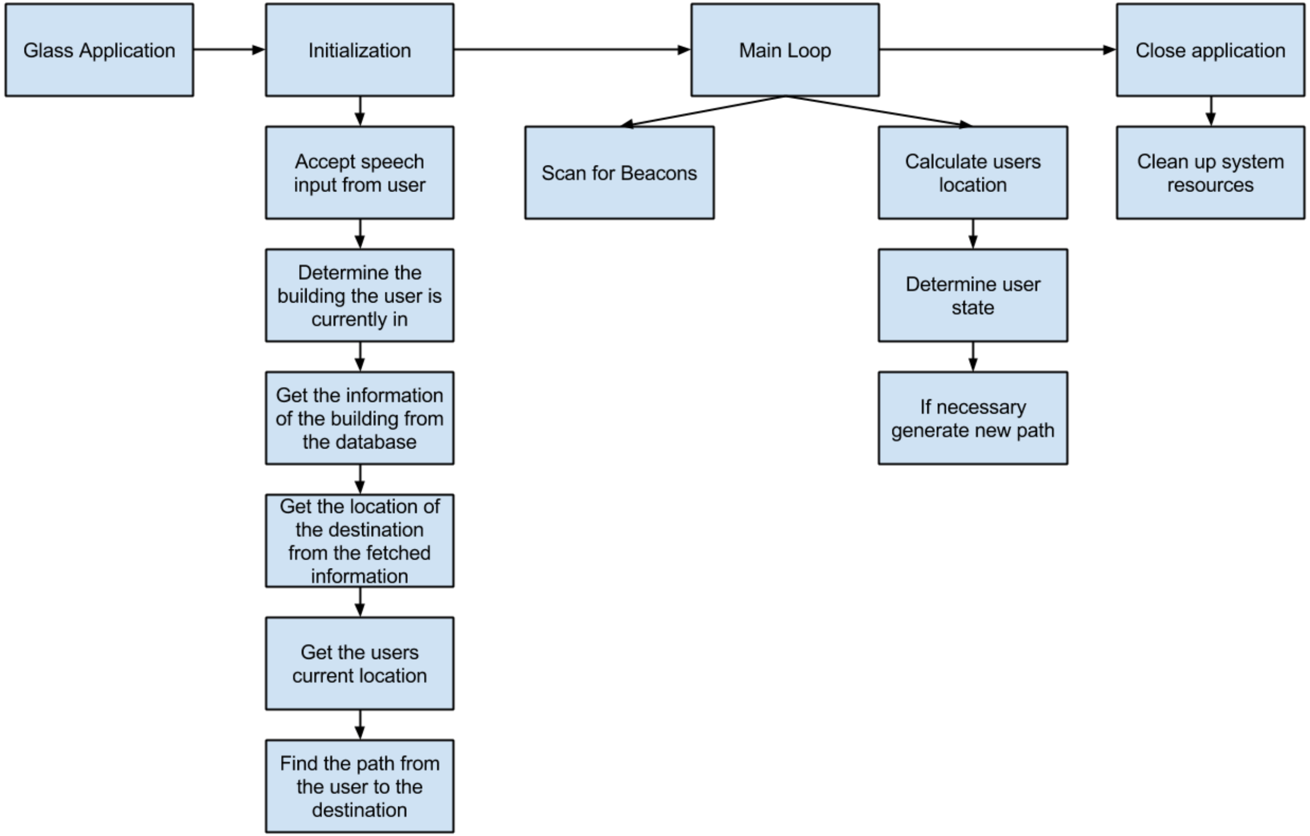
System Design



Specifications

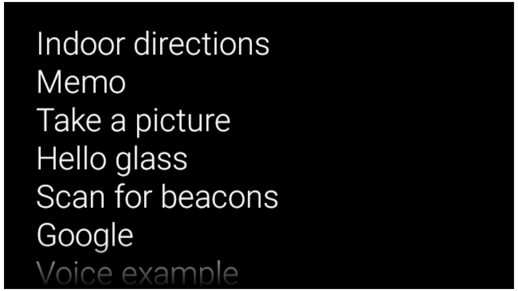
- Software
  - Guide the user (both visually and verbally) within a meter of the destination
  - Low usage of system resources
- Hardware
  - Bluetooth 4.0 compatibility
  - Omnidirectional antenna design
  - Operable Range ~ 5 meters
  - Modular power design

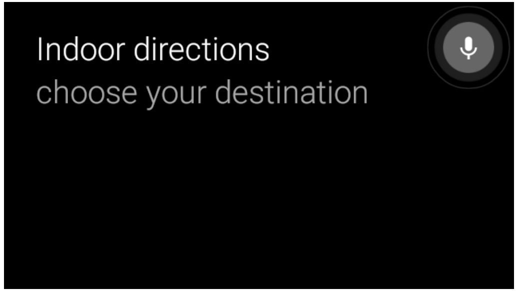
Glass Application



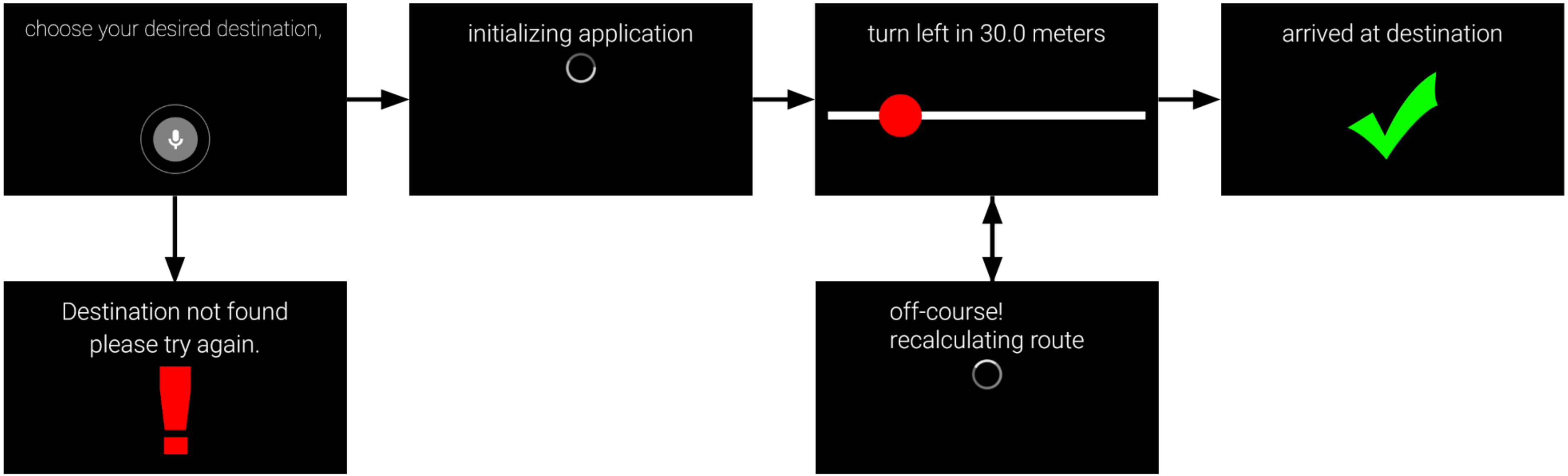
Glass Application

- In order to start the application the user will say the “ok glass” keyword to bring up the application menu
- They will then use the “indoor directions” keyword to start the application
- The user will then be prompted to speak their desired destination



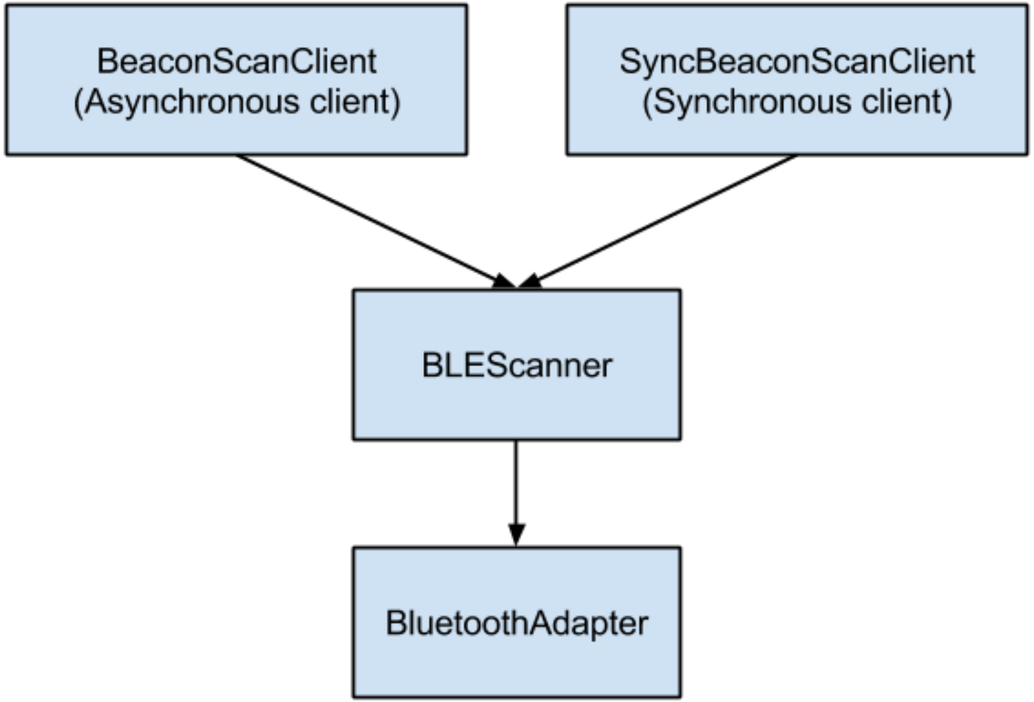


Glass Application



Android Beacon Library

- Wrapper for Android's BluetoothAdapter
- Handles converting Androids native BluetoothDevice objects to our Beacon object
- Filters out BLE devices which aren't Beacons by parsing the signal received
- Includes a synchronous and asynchronous client

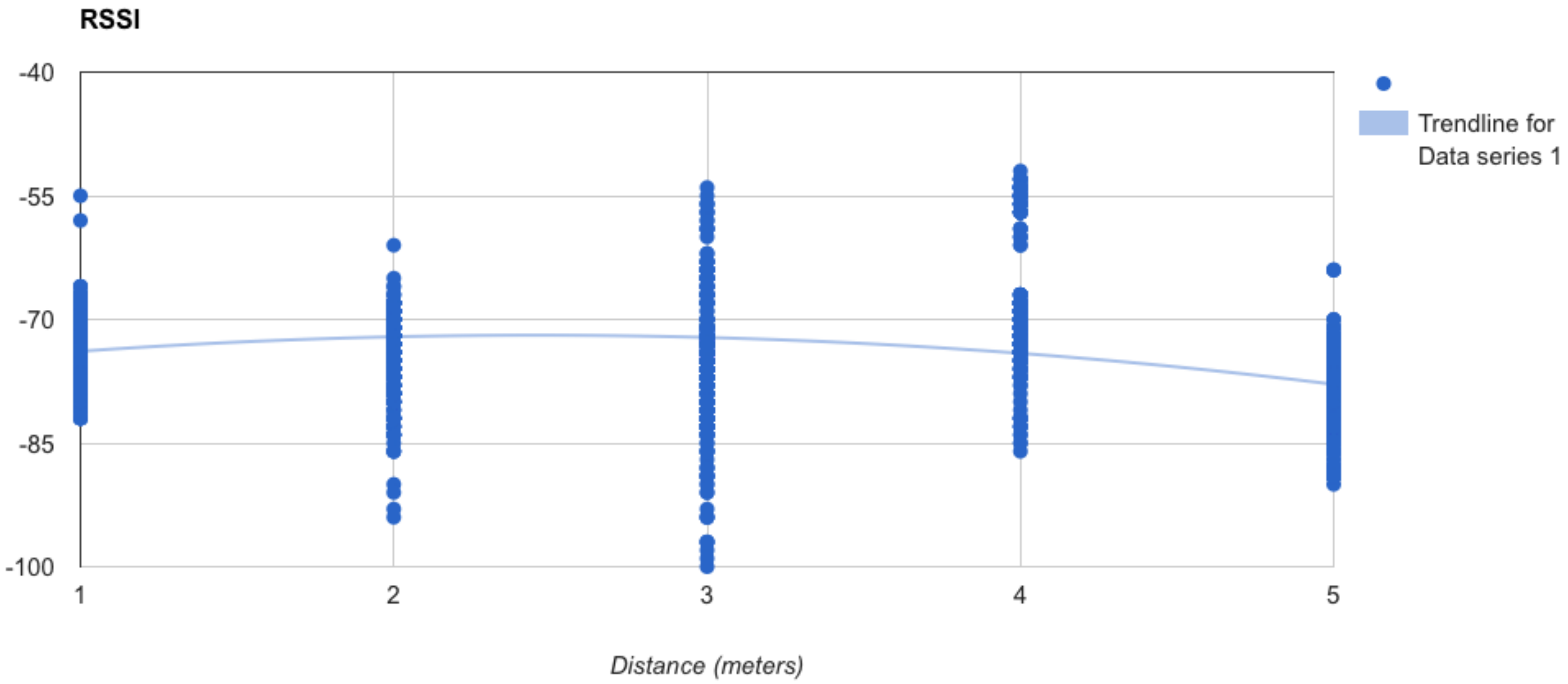


User Localization

- Trilateration initially looked at as a possible solution
  - Uses known approximate distances from user to beacons and known beacon locations to find the approximate location of the user

- Due to inconsistent beacon signal readings, trilateration could not be used
  - Walls and obstacles influence signal reading
  - Movement influences signal
  - Even reading signals while stationary produces inconsistent results
  - Example: Beacon 15 meters away reads as being 25 meters away or 5 meters away

User Localization

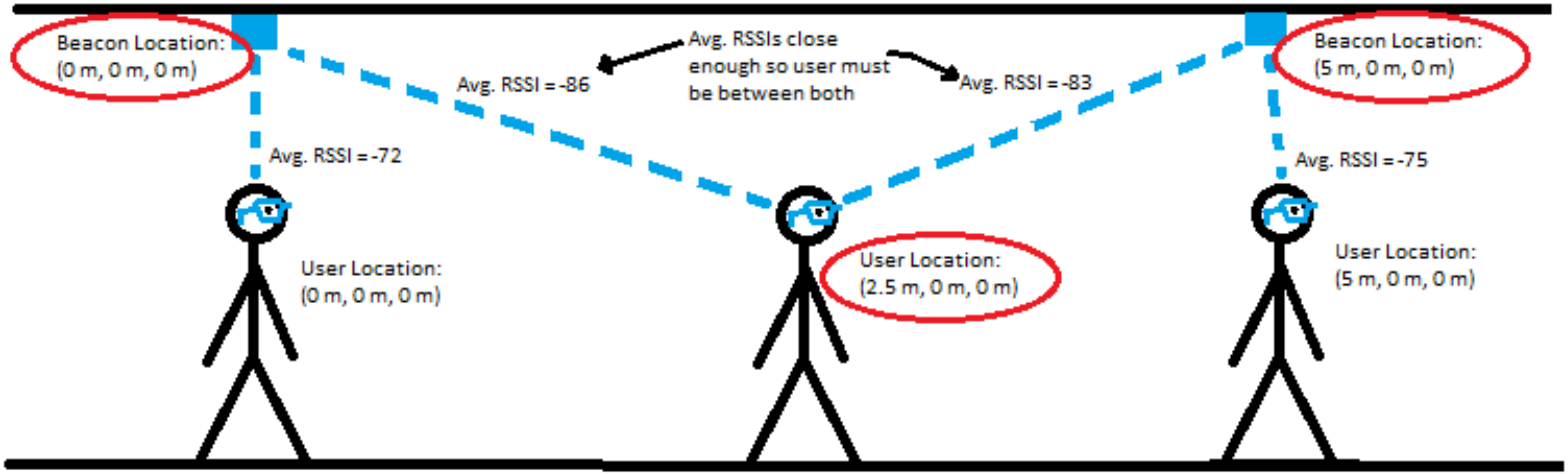


User Localization

- Instead, using beacon proximity to determine the user’s location
  - User mapped to the beacon whose average signal reading is the closest
  - Consistent results can be achieved with this method
  - Downside: User can only be located wherever beacons are placed requiring more beacons

- Optimized by doubling the distance between beacons and snapping the user’s location between two beacons if the average signal from both beacons is similar
  - Reduces the number of beacons needed

User Localization



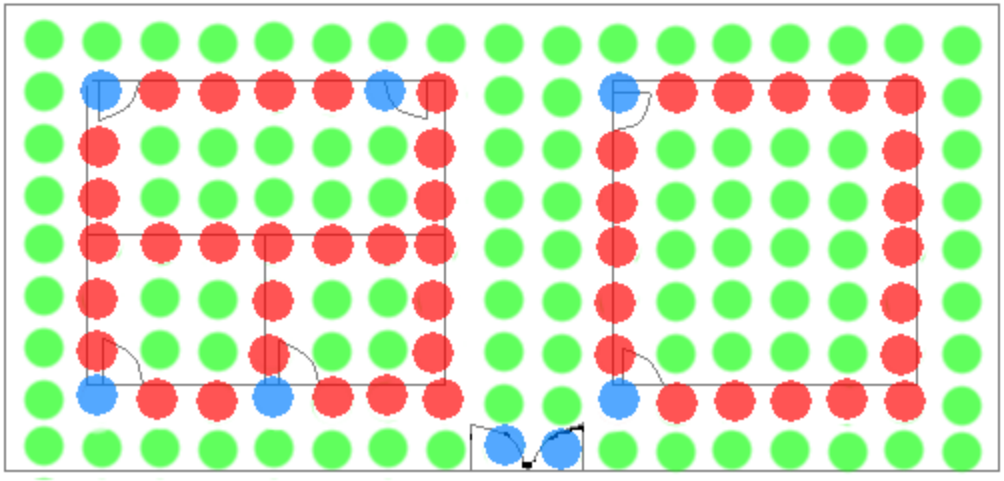
Pathfinding

- Constructs a path between the user’s location and destination using virtual nodes that describe the building’s layout

Green: Walkable areas

Red: Blocked areas

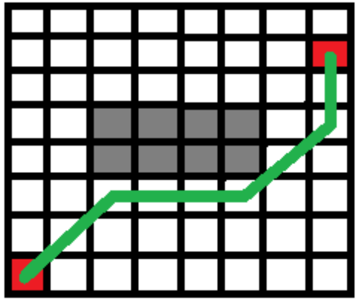
Blue: Possible destinations



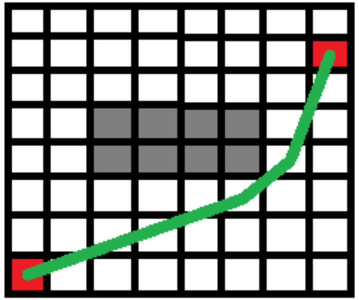
Pathfinding

- Uses Theta* instead of A* for pathfinding on each floor

- Theta* calculates paths with fewer turns allowing for simpler directions because the algorithm incorporates line of sight when determining the path

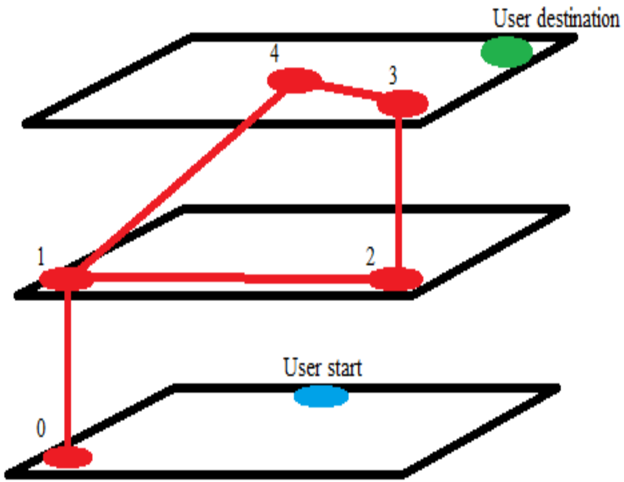


A* Algorithm



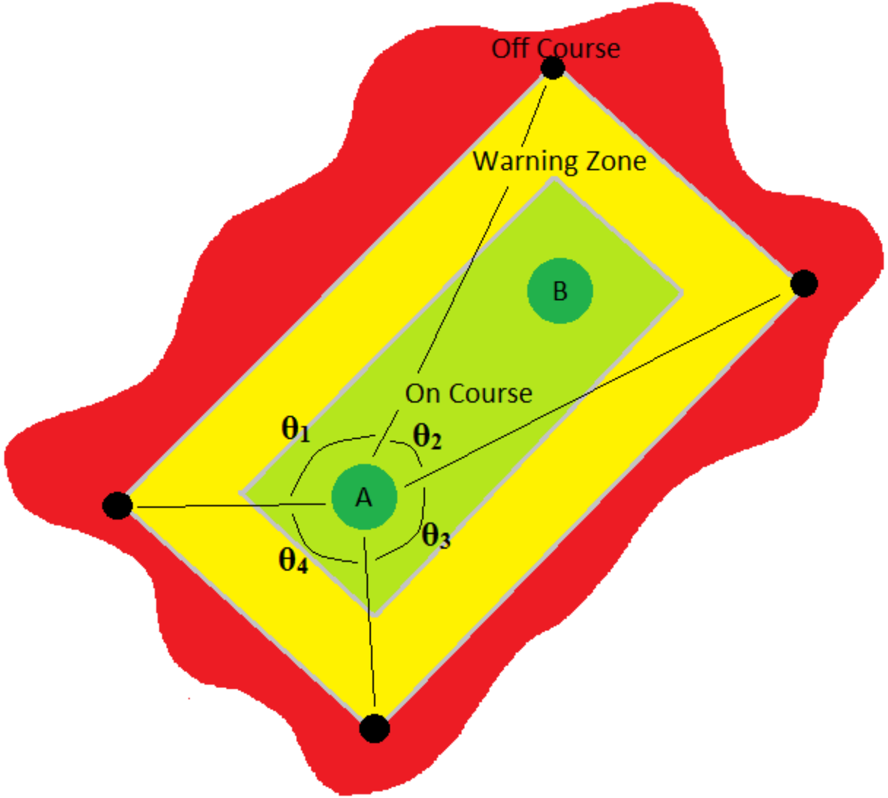
Theta* Algorithm

Floor Sequencing



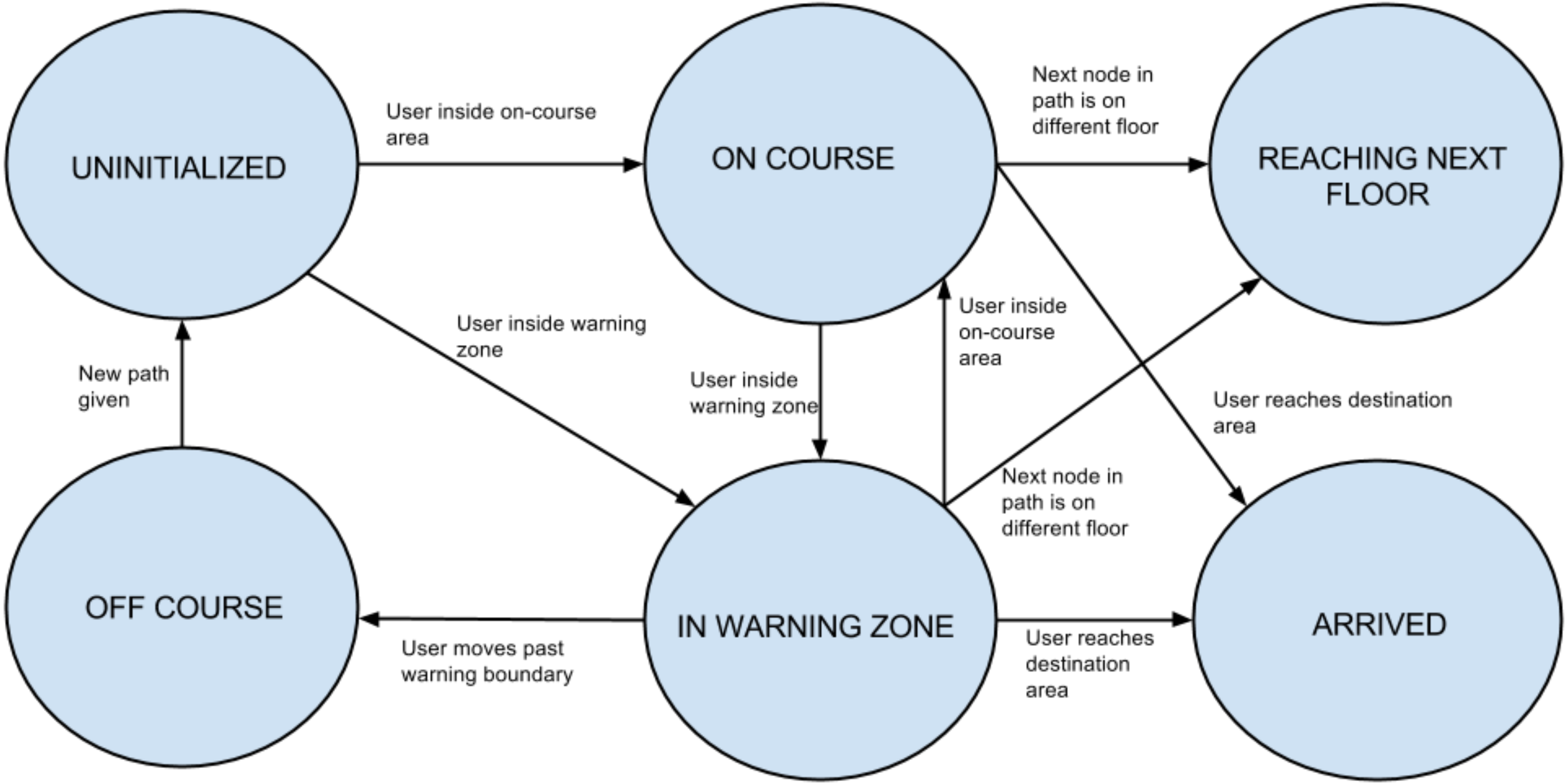
- Handles path planning across multiple floors when the user's destination is on a different floor
  - Links the paths calculated from Theta* together into one multi-floor path
  - Uses an adjacency list holding the connections between floors to link the single floor paths
  - Basic process:
    - Use depth-first search to get all possible ways to get to the destination floor
    - Link together Theta* paths into one multi-floor path

User State Tracking



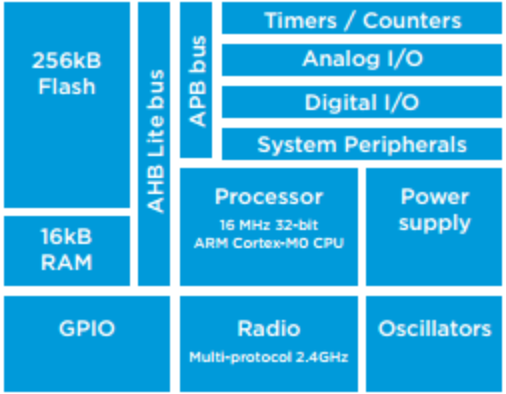
- Determines whether the user is on-course, off-course, or in the warning zone
- Perimeter generated around current node and next node in the path
    - User considered inside perimeter if $\theta_1 + \theta_2 + \theta_3 + \theta_4 = 2*PI$
- The user state is then reported to the system to adjust accordingly

User State Tracking



nRF51822

- “System on Chip”
- QFN-48 package
- ARM 32-bit CPU
- Small form factor
- Low power consumption
- 2.0-3.5 V Input Support
- Integrated 2.4 Ghz transceiver
- Native Bluetooth 4.0 LE or ANT support



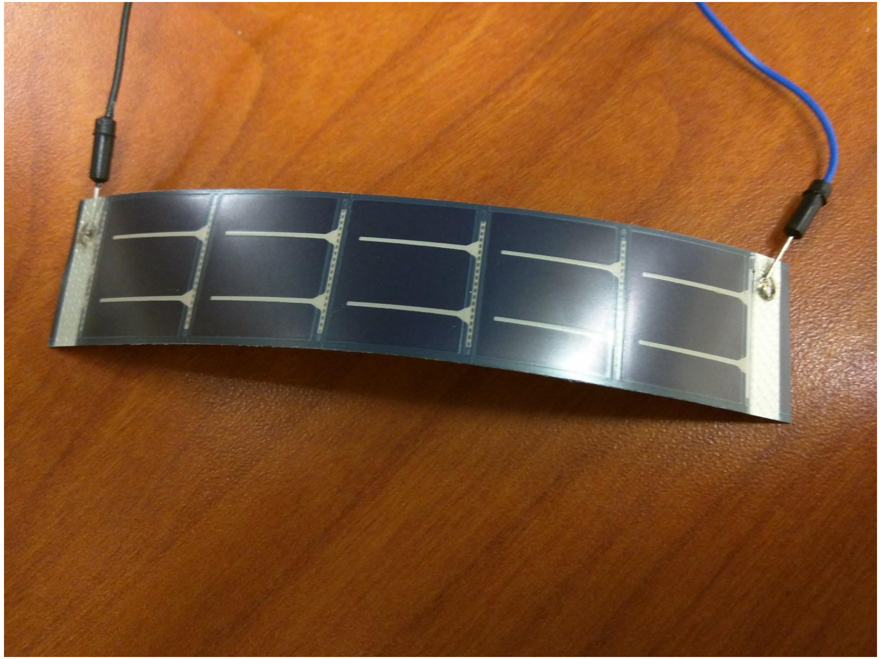
nRF 51822 Product Specifications Datasheet (http://www.100y.com.tw/pdf_file/39-Nordic-NRF51822.pdf)

Power

- Modular input design allowing for a primary and secondary power source
- Our implementation
  - Photovoltaic cell
  - Coin-cell battery

Photovoltaic Cell

- Model: MP3-25
- Used as the Primary source
- Generates up to 3.6 Volts
- Flexible form factor

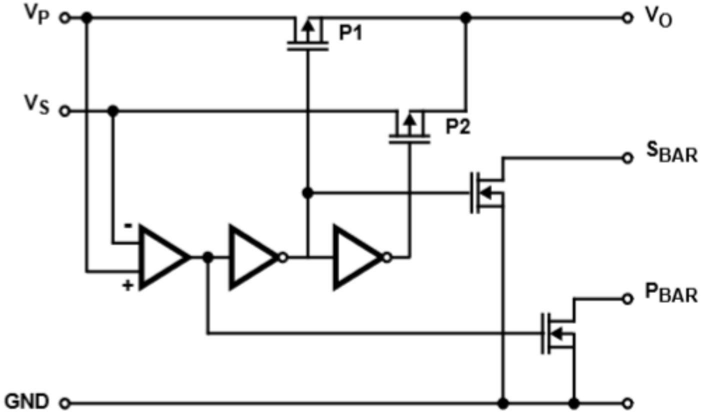


Coin-cell Battery

- CR2032
- Used as a secondary source
- 3.0 volts
- Commonly available size

Battery Management

- Intersil ICL7673
    - CMOS circuit
- Switches to the source with the highest voltage
    - $V_P > V_S$ uses primary source
    - $V_P < V_S$ uses secondary source
- 3 V battery backup
    - If solar power source is lost, the circuits switches to battery power
    - Reconnects to main power when restored



ICL7673 Datasheet http://www.mouser.com/ds/2/465/fn3183-70450.pdf

Crystal Oscillator Circuit

- 732-FA-20H16F12V-AJ3 Epson Crystals
- Small feature size SMD crystal (2 mm x 2.5 mm)
- 20 PPM accuracy for Bluetooth operation

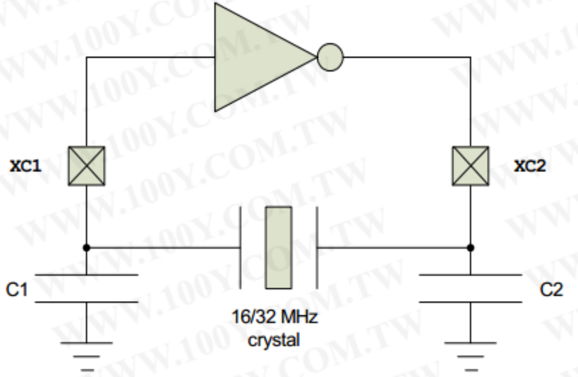


***Figure 6** Circuit diagram of the 16/32 MHz crystal oscillator*

The load capacitance (CL) is the total capacitance seen by the crystal across its terminals and is given by:

$$CL = \frac{(C1' \cdot C2')}{(C1' + C2')}$$

$$C1' = C1 + C\_pcb1 + C\_pin$$

$$C2' = C2 + C\_pcb2 + C\_pin$$

nRF 51822 Product Specifications Datasheet (http://www.100y.com.tw/pdf_file/39-Nordic-NRF51822.pdf)

Radio Scheme

- Antenna Diversity
  - Omnidirectional Antenna
  - Unidirectional Antenna

- Antenna variety allows for optimal coverage in a variety of scenarios; provides for a robust platform

- RF Switch IC AS169-73LF

Omnidirectional Antenna

- Inverted F-antenna
- Radiation pattern spreads to all directions
- 2-layer+ compatible
- PCB Trace Design
- Matched to 50 Ω

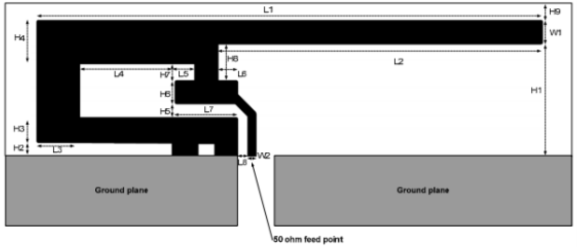


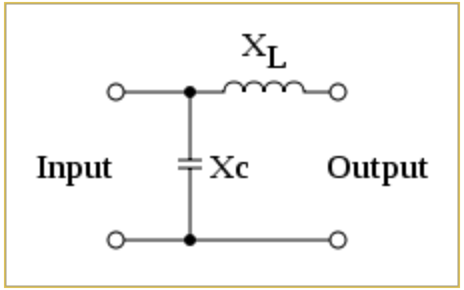
Figure 1. IFA Dimensions

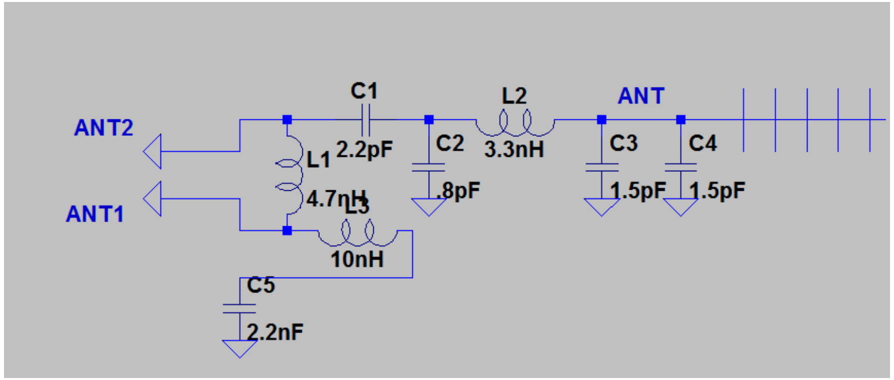
H1	5.70 mm	W2	0.46 mm
H2	0.74 mm	L1	25.58 mm
H3	1.29 mm	L2	16.40 mm
H4	2.21 mm	L3	2.18 mm
H5	0.66 mm	L4	4.80 mm
H6	1.21 mm	L5	1.00 mm
H7	0.80 mm	L6	1.00 mm
H8	1.80 mm	L7	3.20 mm
H9	0.61 mm	L8	0.45 mm
W1	1.21 mm		

Table 1. IFA Dimensions

Antenna Impedance Matching

- Pi Matching Network
  - Normalized to 50 Ω
- Differential Antenna Output to Single-Ended Antenna Output
  - Increased antenna compatibility
- RF Inductor between embedded low-noise power amplifier and pi network
- Alternatives:
  - Balun
  - Matching chip antenna
- Trace Width is an important consideration
  - Normalized to 50 Ω
  - AppCAD

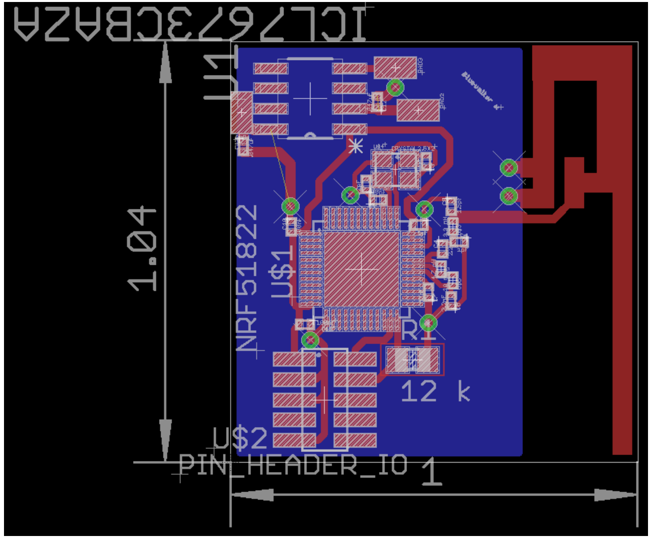




PCB Design Considerations

- Compact design
  - 0402 footprint passive components
  - Tight pitch traces
- RF-friendly passive components
- Large bottom-layer copper plane
  - High speed digital electronic noise reduction
  - Synergizes with antenna
- Considerations:
  - Limit electromagnetic interference of neighboring components and vias
  - Keep layers underneath antenna circuitry clear of traces
  - Short power traces to reduce EMI
  - Decouple to ground quickly

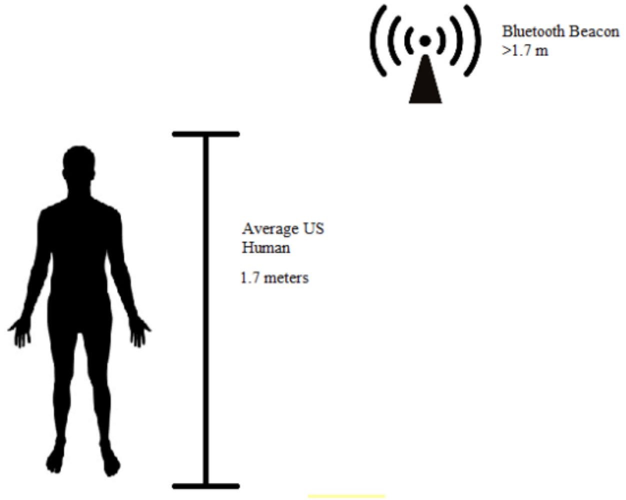
4-Layer	2-Layer
More expensive	Cheaper
Allows for a more compact design	Requires more space



Our board measures approximately 1 square inch; blue is bottom layer and red is top layer; Inverted-F antenna visible on the right

Beacon Placement Optimization

- Situation Area: Engineering 1
- Possible Locations:
  - Ceiling
  - Wall
- Placement height: >1.7m
- Avoid nearby RF interference
  - Site survey
  - e.g. WiFi Access Points



Bill of Materials

Product	Quantity	Price
Smart Beacon by Nordic	1	$31.95
Nordic Development kit	1	$99
Google glass	1	Previously Owned
Solar cell	10	$25
QFN 48-pin breakout testing board and stencil	4	$100
Soldering equipment	multiple	$30
Miscellaneous		$50
Crystals, capacitors, inductors, resistors, pin headers	many	$50
Gimbal Beacons	40	$200
ICL7673	20	$40
nRF51822 nordic chip	25	$100
2 layer PCB	18	$140
Assemble PCB	15	$500
Batteries	-	$100
		$1,465.95

Workload Distribution

Members	Josh	Jonathan	Pedro	Andre
Pathfinding	**X**			
User Localization	**X**			**X**
User State Tracker	**X**			**X**
Beacon Library				**X**
Glass Application				**X**
Power Design			**X**	
Antenna and RF Design		**X**		
RF Optimization		**X**		
Beacon Firmware	**X**	**X**	**X**	
PCB Design		**X**	**X**	

Fragen?

Вопросы есть?

Questions?

¿Preguntas?