ECE496 Implementation Plan

Project Title: Bluetooth Low Energy (BLE) As Localization and Communication Solution for Drone Swarms

Project Number: 2022617

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Executive Summary

This document provides an overview of the drone BLE project solution that aims to demonstrate a scalable swarm drone infrastructure that utilizes BLE AOA technology for both accurate indoor localization and communication between 2 or more drones since GPS localization is limited to only outdoor drone localization.

A major change to the original project proposal is that the drones will be custom-built from scratch using the Seeed Studio XIAO nRF52840 Sense microcontrollers instead of using drone microcontrollers because this provides more freedom to build a simple drone that is controlled using Bluetooth instead of GPS. In addition, this decision reduces the estimated cost of building each drone by 58%, from $198.40 to $83.14, which helps decrease the project budget. This introduced a lot of alternative solutions to the project since the team had to determine what specific parts will be used to assemble the drone and the BLE AOA array. The most important parts decided on are for the drone and BLE AOA array component of the solution: the Seeed Studio nRF52840 microcontroller for the drone flight controller and the uBlox XPLR-AOA-1 BLE AOA boards for the AOA array. The drone design research involved properly connecting DC brushless propeller motors to the Studio nRF52840 microcontroller and finding open-source drone flight control firmware that can be flashed onto it that provides drone control. The BLE AOA array component of the solution is implemented using the uBlox XPLR-AOA-1 arrays since this product provides everything necessary to localize BLE signals due to the GUI software that calculates and displays location information.

As research, design, and assembly have been done on the proposed solution, the project requirements have not changed since the initial project proposal, and they effectively highlight the tests and verifications needed to be completed in the next months of the project. Next, the project management Gantt Chart highlights the status of the milestone completion starting from November when the final parts list was finalized and everything was ordered and received. Since the first project demo, the first iteration of the drone system and the BLE AOA component of the project has been assembled, and thus the remaining milestones involve integrating these components together. During the remaining project timeline, there are still many risks that must be assessed and mitigated in order to complete the project. Since this is a hardware-oriented project, all of our risks pertain to parts being faulty/breaking, running out of parts, or our suppliers running out of stock. Therefore, our mitigations include ordering enough parts so that we have spares, making sure we found multiple suppliers, and also devising a backup plan of using a pre-made drone and modifying it by attaching a uBlox BLE tag that can be used to trace the drone's location in an effort to ultimately demonstrate a functioning proof of concept of using BLE AOA technology for drone localization.

Project Status and Report and Changes

Currently, the specifics of the drone's physical design have been decided, and its parts have been ordered, as shown in *Appendix 1*. We have purchased four *Seeed Studio XIAO nRF52840 Sense* microcontrollers for our Bluetooth Low-Energy (BLE) module and flight controller for the drones along with all the parts needed for the avionics and three *XPLR-AOA-1* BLE AOA boards. As we wait for the parts to arrive, we are working on interfacing with the microcontroller by implementing a way to establish a Bluetooth connection between the module with our personal electronic devices. We are also awaiting final confirmation for the funding for our project, as the expected price greatly exceeds the $100 per person limit, reaching $400 per person for a total of $1,600.

The biggest change we made to our project was to steer our drone design away from off-the-shelf drone parts and build a simple drone from scratch using a microcontroller and custom 3D printed frame. By approaching our design in this direction, we were able to bring down the estimated cost of each drone by 58% from $198.40 to $83.14, which allows us to demonstrate the use of Bluetooth for drone localization using simple drones and establish a stronger case for the feasibility of BLE AOA drones. Furthermore, by implementing our flight controller design, we will be able to better control how the BLE connectivity and control system are implemented.

The components of the project which are implemented and functional are:

- The drone frame has been 3D printed and built with all the components
- DC propeller motors have been tested to ensure they properly spin
- Drone flight controller (*nRF52840* microcontroller) has been tested and observed to be functional: it can turn on, blink an LED, and send Bluetooth packets to a cellular device that control keyboard commands
- BLE AOA antenna array has been tested to localize the position of a BLE tag using uBlox software/GUI

We also chose to move away from Gazebo simulations of the drone system, instead opting for a more rudimentary command-based text simulation for the control system to be implemented. As this project's main goal is to show the feasibility of controlling and locating drone swarms using BLE AOA technology rather than showcasing impressive swarm motions of a drone swarm, it was evident that a physics-based graphical simulation like Gazebo would not be suited for our testing, and because it would require too much time to learn its operations and incorporate our design into the simulated environment.

Possible Solutions and Design Alternatives

Our project includes two main components; the BLE-connected drones and the BLE Angle of Arrival (AOA) antennas. As described in the *project status* section above, we have opted to build a drone with a custom flight controller using an *nRF52840* microcontroller. Although this means that the scope of the project has widened to include the design of a drone and flight controller logic, the benefits this method offers (in addition to the lowered cost per drone) enable us to approach the problem more flexibly. Most importantly, this makes it possible to implement our own communications protocol, which is crucial in reducing the chances of failure in establishing a BLE link between the drone and the ground control station (GCS). Furthermore, achieving the project's goal with a more rudimentary flight controller better showcases the feasibility of BLE AOA as a communication and localization solution.

While off-the-shelf flight controllers and drones were heavily considered, the solution would have been more limited due to the provided software and ports. As these flight controllers are built to work with specific products, it was difficult to find products that would allow us to bypass the need for typical radio transmitters seen in most current drones. These flight controllers would require our team to imitate the communications protocol the radio transmitters use, which would have required an extra microcontroller to accomplish. We believe this approach would have taken a similar amount of effort compared to the custom flight controller approach while costing more than double per drone.

For the BLE AOA antenna arrays, the uBlox *XPLR-AOA-1* board is the solution the team has decided to use since uBlox provides open-source software for the localization algorithm and is available/in stock on multiple suppliers with a very quick shipping time of less than a week (mainly in Digikey, *Appendix 1*). So the team received 1 BLE AOA board quickly in time to test it and understand how it works. An alternative solution was to use the BOOSTXL-AOA antenna board and LAUNCHXL-CC2640R2 development kit from Texas Instruments (TI) [1]. It comes with the provided software needed for the development kit to compute the location of the intersected BLE signal and is open source as well (same as the uBlox GUI). This solution would require work to correctly connect the modules together and flash the software onto the development kit. Therefore, more tasks would be included in the project milestones. The ultimate output of the TI and uBlox BLE AOA modules is the same: localization of a BLE signal. The uBlox solution was clearly an easier option to assemble and use for the project since no assembly is required. However, after reaching out to technical and customer support, it was discovered that the TI BOOSTXL-AOA antenna board is actually obsolete and no longer in production/for sale, so the uBlox board became the prevailing solution for the project.

Technical Design and Implementation

The solution we have pursued can be represented by the system structure shown in Figure 1. This is a system-level overview where the minimum required components needed to achieve the project goal is indicated in red. The project is divided into three subsystems: the Drone System (functioning drones, each with a BLE module), a BLE AOA Array (used for sending/receiving BLE messages and detecting their angle of arrival, which is used to localize the drones), and a Ground Control Station (GCS) used for controlling the drone(s) and tracking their information (Figure 1). Each subsystem is closely intertwined with each module as they all communicate and relay important information to each other, making each module a vital component to the success of our project.

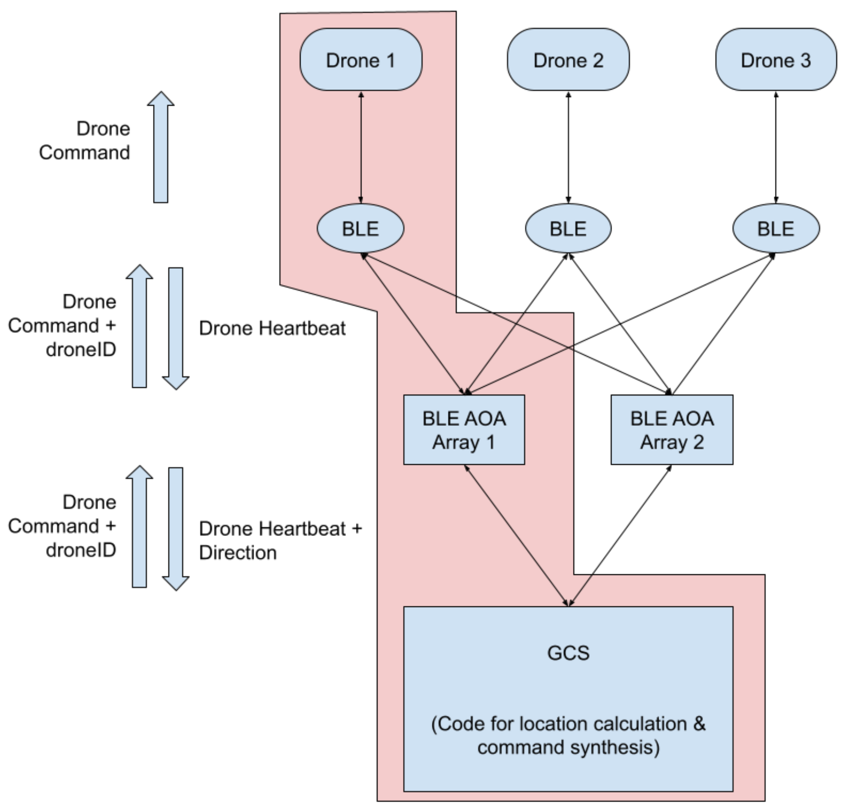


Figure 1 - Representation of the system, with the minimally required system highlighted in red

The intended functionality of the drone system is to be able to send heartbeat BLE signals to the BLE AOA Array System every 0.1 +/- 0.01 seconds. For this reason, it is required that each drone within the system is equipped with a BLE module.

The heartbeat messages that are sent from each drone must include:

- the drone ID number (to know which drone we are communicating with)
- acknowledgement of received motion commands

The desired number of drones within our system is three operating and communicating drones. Another function of each drone is to be able to detect whether it is in the range of the BLE AOA Array system and flip a kill switch (land immediately) if it is outside of the range.

The intended functionality of the BLE AOA Array system is to send and receive each drone's heartbeat to the Ground Control Station within 10 ms of receiving a signal. The system must also calculate the direction of each signal based on the angle of arrival so the location of each drone can be calculated by the ground control station.

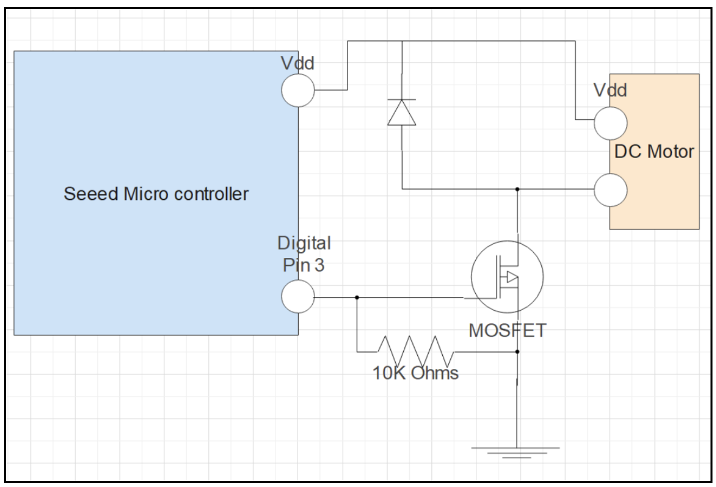


Figure 2: Single motor connection on drone

For the drone's electrical wiring design, we used a MOSFET to design a rudimentary speed controller that uses the analog voltage output to control the current through the motor, as seen in *figure 2*, based on Jovian_Dsouza's design [2]. Because the drones did not require as much agility as commercial drones due to our project's scope being focused on localization, this design should be sufficient.

The intended functionality of the Ground Control Station (GCS) is to determine the location of each drone within a 40-centimetre radius. The angle of arrival information received should be translated to cartesian coordinates within 50 ms. It is also the responsibility of the GCS to ensure that all formulated commands to each drone will not lead each drone out of its communication range, as well as not lead to any collisions between each drone. With respect to control systems, motion planning and collision avoidance are a problem with many existing solutions [3]. Thus any necessary control system used in this project will be outsourced and not implemented from scratch. These algorithms require accurate location data to ensure that the drones will perform their functions correctly. The BLE AOA data is inconsistent and does not match the true location perfectly. Therefore, the location accuracy will be improved [4]. To avoid collisions, multiple ground BLE modules will be used for more reference points, and readings from the gyroscope and accelerometer will be obtained. An averaging algorithm using these multiple data points will be used to refine the location. This algorithm will be repeated as frequently as not to take up too much processing power since other functions need to be performed. After the refined location has been converted to cartesian coordinates, it can not be used by the existing control system to move the drones and avoid collisions. The above information will be presented on the GUI shown in *Figure 3* so the user has a better understanding of the drone's location for easier debugging. The GUI shows a 2D location of the drone with respect to the antenna array. Because the array can only show 2D coordinates, we need at least two array modules to localize the drones in a 3D space.

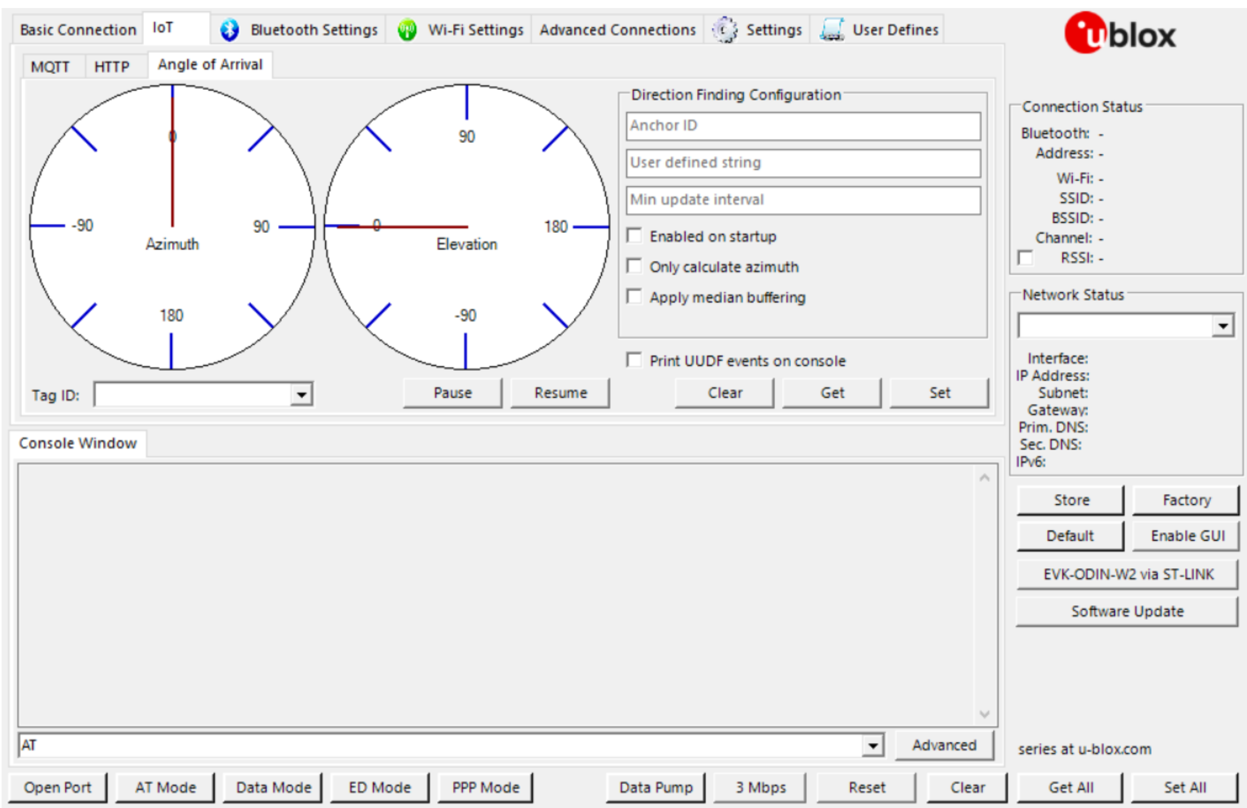


Figure 3: uBlox AOA board GUI that displays localization of BLE tag

Design Specifications

Functions:

- Should be able to broadcast commands to drones and receive information about each drone's heartbeat
  - Heartbeat: signal, drone ID number, acknowledgment of received commands
- The system should be able to detect out-of-bound commands
  - Reject commands that lead to drone motion outside of the signal perimeter
  - Flip a kill switch (land immediately) if a drone manages to leave the signal range
- Drones must not crash into each other
  - Drone can't take/be assigned position in which another drone is already located in (or any position in a 15 cm radius of that point)
- Each drone must be able to complete the following commands: arm (ready to start), disarm, liftoff, land, left, right, forwards, backwards, up, down

Constraints:

- The system must have a latency no greater than 1s between the drone and GCS
- Should be able to determine the location of each drone within an accuracy of 20cm
- A drone must be a quadcopter equipped with a BLE module and a flight controller with embedded electronic speed controllers
- Each drone must weigh less than 250g to qualify within the "micro-drone" class under Canadian law

Objectives:

- The system should be able to accommodate at least 2 drones
- The system should be able to correct any drone's drift up to a 20 cm radius at any given time

Testing and Verification

As the 3 subsystems will be assembled, they will be tested separately as well as a whole to ensure successful system integration. Separate subsystem testing would include: running the drones manually to ensure they function according to the requirements. During the drone design and assembly process, the different components will be tested to ensure they match the project requirements. For example, the drone propellers must be connected and controlled properly to take flight, must communicate using BLE, and must be weighed so it meets the 250g constraint. Integration testing would consist of measuring the latency between the drones and GCS. As the project continues to progress, most of the specified requirements will be tested by performing demos of flying drones in an indoor area with BLE AOA arrays laid out on the floor and checking if they can perform/meet

Project Management

	Task description	Start date	Finish date	Progress
1	**Milestone 1 - Hardware Procurement**	**Nov 14, 2022**	**Nov 25, 2022**	**100%**
1.1	Complete finalized list of hardware parts	Nov 14, 2022	Nov 14, 2022	100%
1.2	**Ordering and receiving parts:**	**Nov 14, 2022**	**Nov 25, 2022**	**100%**
1.2.1	SEEED STUDIO XIAO NRF52840 SENSE board	Nov 14, 2022	Nov 15, 2022	100%
1.2.2	uBlox AOA Board	Nov 20, 2022	Nov 23, 2022	100%
1.2.3	3D printing filament	Nov 20, 2022	Nov 21, 2022	100%
1.2.4	LiPo Batteries	Nov 20, 2022	Nov 22, 2022	100%
1.2.5	Mosfets x 25	Nov 20, 2022	Nov 23, 2022	100%
1.2.6	Diodes x 25	Nov 20, 2022	Nov 23, 2022	100%
1.2.7	DC-DC Boost Converters x6	Nov 20, 2022	Nov 21, 2022	100%
1.2.8	Drone motors (x4) and propellers (x16)	Nov 20, 2022	Nov 25, 2022	100%
2	**Milestone 1.5 (Demo)**	**Nov 21, 2022**	**Dec 2, 2022**	**100%**
2.1	Localization of uBlox tags using AOA board	Nov 23, 2022	Dec 2, 2022	100%
2.2	**Seeed Sense module successfuly working**	**Nov 21, 2022**	**Dec 1, 2022**	**100%**
2.2.1	Successful LED test	Nov 21, 2022	Dec 1, 2022	100%
2.2.2	Can send BLE messages	Nov 21, 2022	Dec 1, 2022	100%
3	**Milestone 2 - Seeed BLE Drone Connection & Localization**	**Nov 26, 2022**	**Dec 23, 2022**	**77%**
3.1	Localization of Seeed BLE modules using BLE AOA Array	Nov 26, 2022	Dec 23, 2022	70%
3.2	**Assembled drone**	**Nov 26, 2022**	**Dec 23, 2022**	**80%**
3.2.1	Drone frame printed	Nov 26, 2022	Dec 9, 2022	100%
3.2.2	4 propeller motors functioning using Seeed module	Nov 26, 2022	Dec 23, 2022	100%
3.2.3	Drone can liftoff and land	Nov 26, 2022	Dec 23, 2022	50%
4	**Milestone 3 - Single Drone System**	**Dec 23, 2022**	**Feb 1, 2023**	**0%**
4.1	Communication between drone, AOA array and GCS	Dec 23, 2022	Feb 1, 2023	0%
4.2	Single drone flight control system	Dec 23, 2022	Feb 1, 2023	0%
4.3	AOA accuracy of drone location is within 20cm	Dec 23, 2022	Feb 1, 2023	0%
5	**Milestone 4 - Multiple Drone System**	**Feb 1, 2023**	**March 15, 2023**	**0%**
5.1	Complete working system with 2 drones	Feb 1, 2023	March 15, 2023	0%

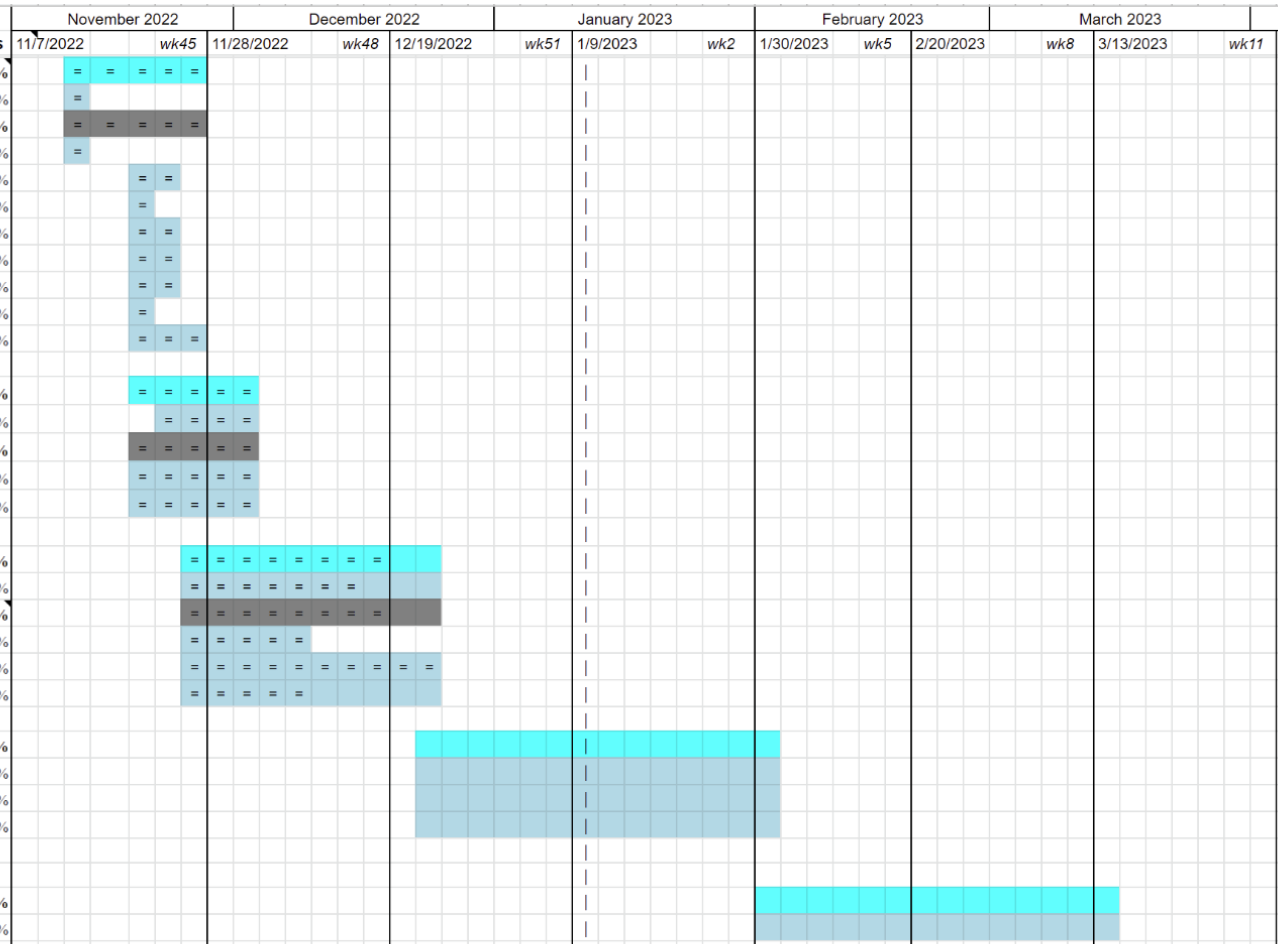


Figure 4 - Project Gantt Chart

Management Plan:

- Task ownership (As of December):
  - Adam - working on flight control firmware
  - Jun Ho - working on drone design and general project management
  - Mohammad - working on SEEED-to-BLE AOA array connection
  - Natalia - working on drone motion control
  - Everyone will work on localization accuracy improvement
- Dependencies between drone and AOA antenna board tasks
  - Seeed Sense module on the drone (microcontroller) must successfully send BLE messages that the uBlox AOA antenna boards can detect (and calculate their AOA)

Risk Assessment

With any project, unforeseen circumstances can lead to the risk of an incomplete project. Due to the uncertainty of time, we've discussed key risks that could occur during the next few months and have reached different strategies to mitigate the effect of these risks.

Due to the nature of our design of custom building our drones from scratch, having parts break is a major risk that can impede the progress of our project severely. This is because having an operating drone is the backbone of our project, which allows us to further explore and make progress toward our goal. If a part breaks and we cannot construct a drone, it would not allow us to further utilize BLE AOA technology to communicate with the drone system we are trying to build. To mitigate this risk, we have ordered additional parts in advance to be able to construct four drones (the drone swarm goal is to have only 2 working drones). The additional parts ordered to construct a third drone will be used as spares when constructing the first two drones in case any parts appear to be faulty/broken.

Since our drone is being designed by us and is being constructed ourselves, there is a chance that the final drone product does not function or work. However, the design of our drone and the parts ordered were thoroughly researched in advance and having an experienced group member who has constructed drones on his own before makes us believe this is a low-risk issue. We do still have a plan however to mitigate this risk which is to purchase an already-existing drone and attach a uBlox tag for localization evaluation. This would help us accomplish a part of our goal as it will show the accuracy is sufficient enough for localization.

Another risk related to the construction of the drones is that the parts ordered may not be the correct size and may not fit together with other parts. As we're custom building these drones, it is crucial that each part we order comes in the right size and can fit with each of our other parts. To mitigate this risk of error, as a group we decided to cross-check the selected parts before ordering. This allows the entire group to gain experience in researching appropriate parts and ensuring the selected parts have no sizing issues.

A risk of less concern regarding the ordering of our parts is that the company we are ordering from goes bankrupt or out of service. If this were to happen, it could potentially cause a delay for our team to receive the parts further delaying our ability to make progress with our project. To mitigate this risk we thoroughly looked at our options when selecting a company to order from, ensuring we have experience working with them before they are reliable and trustworthy. In the case that our selected distributor (DigiKey) is unable to fulfill our orders, we have a backup company to order from (Mouser) which has the same quick one to three-day delivery times ensuring no major delay or halt to our project.

References and Appendices

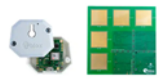
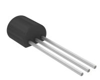
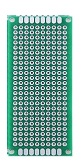
[1] "Launchxl-CC2640R2," *LAUNCHXL-CC2640R2 Evaluation board | TI.com*. [Online]. Available: https://www.ti.com/tool/LAUNCHXL-CC2640R2. [Accessed: 09-Jan-2023].

[2] Jovian_Dsouza, "Cheap Arduino drone using Bluetooth," *Instructables*, 28-Feb-2021. [Online]. Available: https://www.instructables.com/Cheap-Arduino-Drone-Using-Bluetooth/. [Accessed: 09-Jan-2023].

[3] M.M. Iqbal, *et al.,* "Motion planning of UAV SWARM: Recent challenges and approaches, IntechOpen," *IntechOpen*, June 2022. [Online serial]. Available: https://www.intechopen.com/online-first/82985. [Accessed: 24-Oct-2022]

[4] "AoA Receiver," *Texas Instruments*. [Online]. Available: https://software-dl.ti.com/simplelink/esd/simplelink_cc2640r2_sdk/2.30.00.28_new/exports/examples/rtos/CC2640R2_LAUNCHXL/blestack/aoa_receiver/README.html. [Accessed: 24-Oct-2022].

Appendix 1 - Project parts list purchased

Part Name	Image	Purpose	Unit Cost	Quant.	Total Cost
[1] XPLR-AOA-1 (BLE AOA Board)		Must have for BLE AOA system.	$373.11	3	$1119.33
[2] Seeed Studio XIAO nRF52840 Sense (Arduino Board)		Main microcontroller for drone & BLE module + IMU.	$25.06	4	$100.24
[3] 3d-printing filament		Required to 3d-print frame	$33.99	1	$33.99
[4] 8.5 x 20mm Brushed Motors + 55mm CW CCW Propeller		Drone parts (motor + propellers)	$19.27	4	$77.08
[6] Fytoo 5Pcs 3.7V 1200mah Upgrade Li-Polymer Battery		Drone parts (battery)	$35.99	1	$35.99
[7] MT3608 DC-DC boost converter (pack of 6)		Drone parts (Microcontroller voltage)	$10.49	1	$10.49
[8] TN0702N3-G		Drone parts (mosfet for motor control)	$1.9428	25	$48.57
[9] 1N5817-TP		Drone parts (diode for motor control)	$0.39	25	$9.75
[10] Printed Circuit Protoboard		Drone must be soldered together on this board	$21.99	1	$21.99

Total cost (Incl. tax & Shipping) = $1630.32

Appendix 1a - URLs to each product in Appendix 1

1. https://www.digikey.ca/en/products/detail/u-blox/XPLR-AOA-1/14549114?fbclid=IwAR3k5VZjX66F7ShL8c7aWn6LkvkIc2r7w_MWlxSzp_wnh6KT42nRtjb_iG4
2. https://www.digikey.ca/en/products/detail/seeed-technology-co-ltd/102010469/16652896?s=N4IgTCBcDaIIwAYwMQFgGwE4QF0C%2BQA
3. https://www.amazon.ca/AMZ3D-1-75mm-Printer-Filament-Black/dp/B01BZ5ND8O
4. https://www.amazon.ca/YoungRC-Coreless-Brushed-Propeller-Quadcopter/dp/B078NL9KQQ/ref=sr_1_12?crid=2WGL7HZKSPT86&keywords=drone+dc+motor&qid=1668567764&qu=eyJxc2MiOiIyLjk0IiwicXNhIjoiMC4wMCIsInFzcCI6IjAuMDAifQ%3D%3D&refinements=p_85%3A5690392011&rnid=5690384011&rps=1&sprefix=drone+dc+motor%2Caps%2C119&sr=8-12
5. https://www.amazon.ca/BETAFPV-3-Blade-Propellers-Meteor65-Quadcopter/dp/B081C6NX8Y/ref=sr_1_5?crid=ISDATAEYC2Q5&keywords=micro+drone+propellers&qid=1668567371&qu=eyJxc2MiOiIyLjE5IiwicXNhIjoiMC4wMCIsInFzcCI6IjAuMDAifQ%3D%3D&sprefix=micro+drone+propellors%2Caps%2C63&sr=8-5
6. https://www.amazon.ca/Fytoo-Li-polymer-Batteries-Quadcopter-Replacement/dp/B0795CJWPB/ref=asc_df_B0795CJWPB/?tag=googleshopc0c-20&linkCode=df0&hvadid=335213580686&hvpos=&hvnetw=g&hvrand=2668537867823253935&hvpone=&hvptwo=&hvqmt=&hvdev=c&hvdvcmdl=&hvlocint=&hvlocphy=9000929&hvtargid=pla-784912314206&psc=1
7. https://www.amazon.ca/AIHJCNELE-MT3608-Adjustable-Transformer-Stabilizer/dp/B09Z38RV4H/ref=sr_1_3?keywords=MT3608&qid=1668570377&qu=eyJxc2MiOiIzLjU3IiwicXNhIjoiMi43OCIsInFzcCI6IjMuMTEifQ%3D%3D&s=electronics&sr=1-3&th=1
8. https://www.digikey.ca/en/products/detail/microchip-technology/TN0702N3-G/4902376
9. https://www.digikey.ca/en/products/detail/micro-commercial-co/1N5817-TP/950394
10. https://www.amazon.ca/gp/product/B074X2GDH2/ref=ppx_yo_dt_b_asin_title_o00_s00?ie=UTF8&psc=1