Open-Source Prototyping of 5G Wireless Systems for Unmanned Aerial Vehicles

DESIGN DOCUMENT

Team 13

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Executive Summary

Development Standards & Practices Used

- 3rd Generation Partnership Project (3GPP) Specifications
- Small Cell Forum FAPI and nFAPI Specifications
- IEEE 802 family of standards
- Agile framework with Scrum methodology
- Open-source software utilization
    - Open Air Interface (OAI)
    - New Paparazzi Simulator (NPS)
    - JSBsim Flight Dynamics Model (FDM)

Summary of Requirements

- Integrated simulator should be able to successfully simulate communication among UAVs on a 5G wireless system
- Simulator should be able to consider outside weather conditions and environmental hazards when scheduling UAV routes
- Simulator should be open-source and free to use among the research community

Applicable Courses from Iowa State University Curriculum

- ENGL 314 - Helped in the creation of reports, checking for grammatical errors, and outlining of reports
- SE/COM S 309 - Early project experience helped facilitate working and operating within a team
- COM S 352/CPRE 308 - Understanding of operating systems necessary for implementing drone software and navigating Linux
- CPRE 489 - Computer Networking and Data Communications helped in understanding client server programming, data and routing protocols and most importantly local area networks.

New Skills/Knowledge acquired that was not taught in courses

- 5G implementation knowledge
- Drone development and simulation
- Usage of simulation software and Linux distribution such as Ubuntu

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- UAV - Unmanned Aerial Vehicle
- OAI - OpenAirInterface (5G/LTE simulator)
- NPS - New Paparazzi Simulator
- C-A2X - Cellular to Aerial Vehicle to Everything Communication
- C2A - Cellular to Aerial Vehicle Communication
- A2A - Aerial to Aerial Vehicle Communication
- UE - User Equipment
- eNB - eNodeB, Base Station
- PDCP - Packet Data Convergence Protocol
- RLC - Radio Link Control
- MAC - Media Access Control
- PHY - Physical Layer
- nFAPI - Network Functional Application Platform Interface

1 Introduction

1.1 Acknowledgement

We thank Professor Zhang for all the assistance in the guidance of this project, as well as the provision of other sources of information for Drone Simulation, OAI setup, and remote access to computers.

1.2 Problem and Project Statement

Inter-vehicle communication for unmanned aerial vehicles is needed to improve the safety and sensing capabilities for autonomous functionality. Current 4G, LTE network architecture does not meet the latency requirements to ensure reliable inter-vehicle communication. Our group will implement a next generation 5G wireless network simulation and real-time scheduling algorithms to demonstrate reliable transfer of packets between vehicles.

Our project will focus on the implementation of 5G networks for unmanned aerial vehicles, or drones, and real-time scheduling algorithms associated with communication among these vehicles. We will simulate how drones can be improved with 5G, while also staying efficient, safe, and cost-effective. This simulation will have applications in areas such as drone delivery, agricultural surveillance, and search and rescue drones.

1.3 Operational Environment

Our simulation should be able to take outside weather conditions into consideration when planning vehicle routes. We assume that drones will be able to handle and plan accordingly to common weather hazards, such as wind, rain, and snow. Drones will also need to be aware of other hazards in their environment such as large buildings or structures and other drones in their route.

1.4 Requirements

The primary functional requirement for our project is for our software simulation tool to be able to simulate communication between UAVs on a 5G wireless system. Our simulator will need to consider environmental factors such as weather conditions and avoid obstacles such as buildings or structures. The simulator will be open-source and free to access by others in the research community and beyond.

1.5 Intended Users and Uses

We expect our project to be used and referenced in academia and beyond. More specifically, we expect both students and faculty to be able to reference the work in this project, as well as implement and use the algorithms we will describe later in our project. We also expect researchers and engineers to be able to build off of our work on the project.

1.6 Assumptions and Limitations

Assumptions	Limitations
• Used by research professionals and network developers • Small scale development versus a large, ready-to-ship version	• Limited knowledge of networking • 2-semesters to finish project • Lack of previous knowledge with 5G • Open-source code for 5G simulation is still being developed

(Fig. 1: Assumptions and Limitations Table)

1.7 Expected End Product and Deliverables

Goals

- Understanding how to use OAI and other multi-domain simulators by downloading and running OAI and NPS in Linux Ubuntu.
- Integrating OAI with simulators to run drone simulations in 5G wireless systems.
- Extend existing networking algorithms for C-A2X (Cellular to Aerial Vehicles to Everything).
- Test networking algorithms using integrated OAI simulator for drones.
- Perform field testing of a real-world drone delivery system and document research findings in a scholarly paper.

Our expected deliverable for our first semester is getting used to OAI and UAV simulators. The main goal for the first semester is understanding and integrating OAI with multi-domain simulators. Once we are comfortable and understand how to use these programs we will be focusing on starting drone simulations for our second semester. We hope to use the experience from these simulations to prototype a drone and test in the real world. The discoveries and experiences of our project will then be documented in a scholarly article.

2 Project Plan

2.1 Task Decompositions

For this project, we have broadly separated our tasks into two categories: Software side, and hardware side. For our software, we expect to be improving upon the already existing algorithms that exist in OAI and other simulations, as well as being able to run multiple simulations simultaneously.
As for the hardware side, we're focusing on developing a way to implement our software algorithms and simulations into a microcontroller and casing, in order to prove that our software will work in a real-working prototype.

2.2 Risks And Risk Management/Mitigation

The main risk we face, in the entirety of our project, is the commitment of time needed by all the group members to succeed in this project. For this, we plan to, again, run a Scrum-like system of task management, where each of us tackle a task, or story, for a sprint, or every two weeks. This way, we ensure each member has sufficient time to complete their tasks while not burning themselves out.
Another slightly different risk we face, is the recent emergence of 5G. While it provides a unique opportunity to shape 5G as we desire, it also leaves us with a lack of experts to turn to, as well as an overall inexperience to the subject and implementation. We plan to combat this by educating ourselves as much as we can, as well as documenting and sharing knowledge with one another as much as possible, to ensure that all parties in the group are as educated and knowledgeable of the project as possible.

Specifically, when working with OAI, the software is constantly evolving and features of the program often change. This presents a risk when trying to run parts of the project that have become obsolete or no longer supported. To mitigate this risk we will need to read the documentations carefully and the feature list for the release we are working with to know which features are supported and we can use.

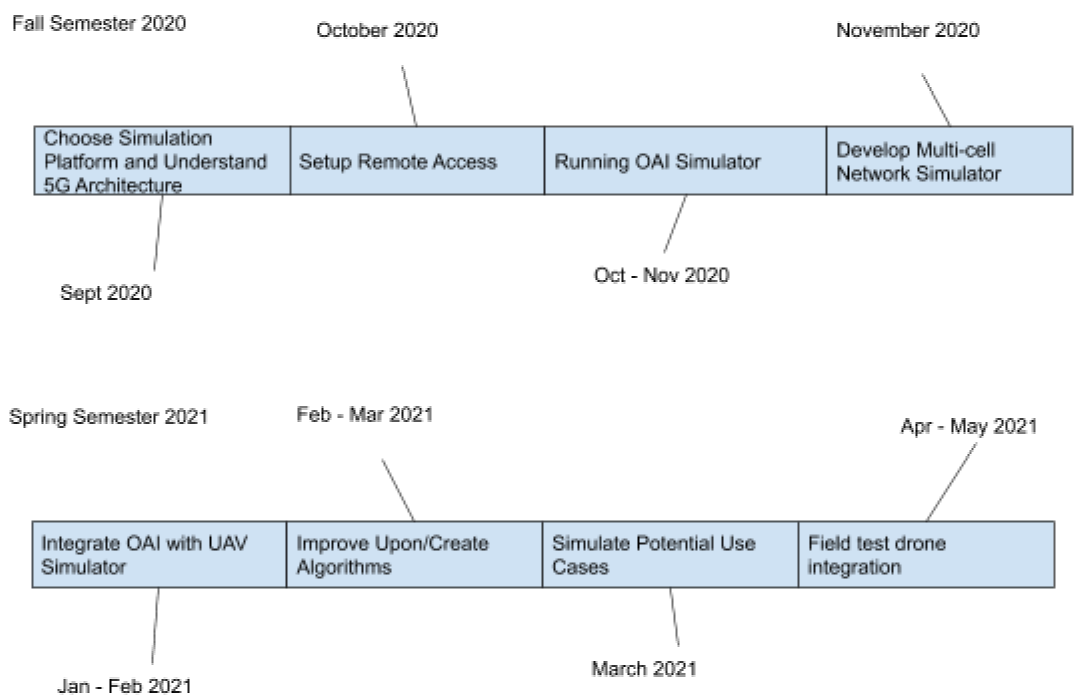
2.3 Project Proposed Milestones, Metrics, and Evaluation Criteria

Some key milestones for the project are as follows:

- Fall 2020:
    - Choose software Simulation/Platform
    - Refine OAI to support integrated OAI and drone simulation
    - Understand existing networking algorithms widely used in industry
- Spring 2021:
    - Create our own networking algorithm for communication among air vehicles
    - Get a single drone to simulate landing and departures to a destination
    - Simulate multiple different drone delivery routes
    - Compare different A2X Algorithms with simulation
    - Write a magazine article to summarize results (software/system development, research findings)
    - Field testing and drone delivery system

As we progress through our project, we will be measuring these test cases against ourselves, and our advisor/client. We'll also be evaluating this through three different processes: where the team will be going through any milestones hit, reviewing if it was a "success" or a "failure", then pass it onto the advisor. If the advisor clears it, the team will then review it once more with the advisor for the final yes or no. At that point, if all 3 cases are passed, the milestone will be considered a success.

2.4 Project Timeline/Schedule

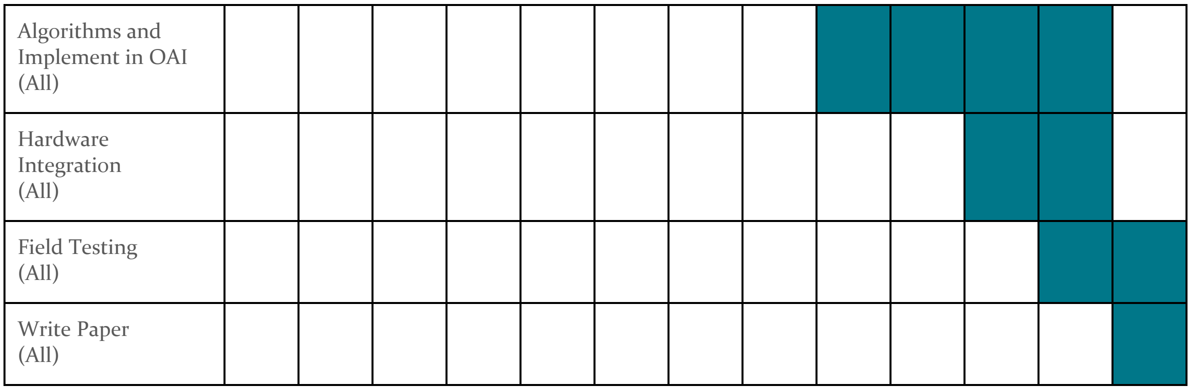


(Fig. 2: Project Timeline)

- Choose simulation platform and understand 5G architecture
  - Experiment with different simulations and choose which best suits our project.
  - Read Wireless Networked Articles and 5G and LTE architecture concepts.
- Setup remote access
  - Gained access to a computer in Coover. Install Ubuntu 16.04.
  - Work with installing OAI and PaparazziUAV.
- Running OAI simulator
  - Setup operating system (Ubuntu) in low-latency kernel mode
  - Build the executables
  - Run the existing single-cell network simulation
- Develop multi-cell network simulator
  - Find different efficient ways to solve drone communication and path mapping using 5G network.
- Integrate OAI with UAV simulator
  - Experiment with different solutions to use OAI and Paparazzi.
  - Simulation will be able to set up 5G networks using multiple drones.
- Improve upon/create algorithms

    - Determine if we must begin the creation of our own algorithms to solve our simulation problems
    - After determination of algorithms we will use, begin the process of refining them to be used for specific purposes
- Simulate potential use cases
    - Using our simulation, be able to simulate different routes for potential use cases
    - Be able to communicate with other objects (C-A2X) using 5G.
- Field test drone integration
    - Reach out to a professor doing related work with drone systems about conducting a field test.

Task Name	8/17-8/30	8/31-9/13	9/14-9/27	9/28-10/11	10/12-10/18	10/19-11/1	11/2-11/15	1/25-2/7	2/8-2/21	2/22-3/7	3/8-3/21	3/22-4/4	4/5-4/18
Read 4G/5G Textbook (All)													
Install OAI (All)													
Install Paparazzi UAV (All)													
Get familiar with OAI (Daniel, Suraj)													
Setup Remote-Access Computer (Ryan, Tyler)													
Run OAI Simulator (Daniel, Suraj)													
Configure Remote-Access Computer (All)													
Run OAI Simulator with multiple eNB and UE (Daniel, Suraj)													
OAI/Paparazzi Integration (Ryan)													
Understand existing Networking Algorithms (Tyler?)													
Extend existing Networking													



(Fig. 3: Gantt chart)

2.5 Project Tracking Procedures

We will be using an Agile framework using Scrum methodology for project management and software development. To do this we will be using Trello to create and assign tasks and insure that our team is meeting needs specified by our client. To manage our code we will be using GitLab and Git for version control. For communication, our team uses Microsoft Teams for messaging and weekly video conferences and Zoom meetings for calls with our client and faculty advisor.

2.6 Personnel Effort Requirements

Tasks	Hours
Research	Expect to spend about 30-40 hours on research, alone, for the project. This is because none of us have prior experience with 5G simulation, thus all of us need time to comprehend the subject. Total: 40 hours
Software Integration	This will be the bread and butter of the project. Thus, we expect to spend much of our time with the integration of simulation and development. Thus, throughout 2 semesters, we expect to spend around 5-10 hours per week on the integration.
Algorithm Design	Algorithm design is another large part and concept of our project. So, this will be very similar and hand-in-hand with our software integration. As such, we expect to spend around 5-10 hours on algorithmic design.
Field Testing	We will spend as much time as we can on this portion of the project. It is dependent on when we finish the project and we will spend the remaining time in the semester testing and using our software.

Documentation	Documentation will be done throughout the two semesters. We should spend roughly 2 hours each week working on scheduling, reports, and the design document.

(Fig. 4: Personnel Effort Table)

In terms of time spent on the project our team has decided that we will individually spend roughly 10-12 hours per week on our tasks. This is divided up into categories in the table above. The beginning will mostly consist of researching topics and getting more familiar with the tools/simulations that we will be using. First step will be the research portion of the project. We expect to spend 10 hours a week on this and it will end up being around 40 hours total. After this we will begin our design. This will be done in a parallel manner spending roughly 10 hours on either the software simulation or algorithm design. We expect to complete this portion of the project by the end of the Fall 2020 semester. After we are completed we will spend the remaining time testing our simulation and possibly setting up a real field test. We will also be spending about 10 hours a week on this. Finally, we have our documentation and we expect to spend roughly 2 hours a week making sure everything is organized and up to date.

2.7 Other Resource Requirements

Professor Zhang, our advisor/client, has been very kind in the lending of a possible group computer to use for this project, as well as providing a sizable list of academic resources used to get a better grasp on the project and what is necessary for us to be successful.

Again, later in the project we would like to possibly build a working prototype if time allows. At the time that we decide, we will make a list of parts and tools necessary for the build.

2.8 Financial Requirements

Almost all simulation software is free to the public and able to be used freely. As such, we do not foresee an immediate need for financial resources at this point in time.
Later in the project, we would like to possibly be able to build a prototype, if time permits. As such, we will gather a list of possible parts and resources needed to complete the prototype then.

3 Design

3.1 Previous Work And Literature

5G is a fairly new technology and there is a limited amount of research that has been done. Given this we are using some existing products in the market and expanding on them. OAI (OpenAirInterface) and Paparazzi (UAV Simulator) are two products that we are using. Our goal is to expand on these products so we can use them together. We want to be able to use OAI with Paparazzi to establish 5G communications between our drones and everything around it. Another part of our project is expanding off previously developed networking algorithms. We will be expanding this algorithm(s) to fit our project's needs.

There are some advantages and disadvantages that come with expanding on these products that are already in the field. Advantages included not starting from scratch, being able to learn from them, and ease of use. Without OAI and Paparazzi already developed we would have to start from nothing and this project would be much more difficult. We can also use these products as learning tools to get us more familiar with 5G and flight simulators. There are also a few disadvantages including having to learn and master programs that we have never used before and compatibility issues that we may run into.

Overall, our project is an expansion and integrated version of two existing products.

References to products used in our project

OpenAirInterface - https://www.openairinterface.org/

PaparazziUAV - https://wiki.paparazziuav.org/wiki/Main_Page

3.2 Design Thinking

Our research focuses on simulating Unmanned Aerial Vehicles (UAV's) in a 5G wireless space. Our design is shaped by the usability of our simulations and effectiveness of it. Our goal is to provide industry professionals with key insights on how OAI and UAV simulators interact with each other through our research. We also hope to expand and further develop networking algorithms to allow for better functionality of UAV's, and other electronic devices in the 5G network space. We hope to implement this by being able to integrate a chosen UAV simulator inside of OAI, in order to better simulate UAVs in a stable environment. Additionally, we also hope to implement 5G algorithms inside of the OAI and UAV simulation in order to best utilize the budding new network, while also increasing the speed at which UAVs can communicate and operate seamlessly.

3.3 Proposed Design

So far, we have been trying to run an OpenAirInterface 5G simulator for simulating multiple UE (user equipment) to one eNB (eNodeB base station). This specific simulation framework meets our functional requirements for simulating inter-drone communication across a 5G network because the framework consists of multiple UE, which can be represented by drones or aerial vehicles, on the same network. Once we have finished getting the 5G simulator working, we will work on integrating a flight simulator tool to get a combined simulator of aerial vehicles on 5G wireless systems. We will need to follow 3GPP specifications for 5G/LTE and make sure that our simulator meets the standards set by IEEE's 802 family of standards.

3.4 Technology Considerations

With 5G being such a new and emerging technology, all of us hadn't experimented too much with the ideas and algorithms that we need to use in order to implement the project. As such, the unfamiliarity of the project was a major downside for us.

At the same time, because 5G is such a new type of technology, we were able to shape our project and ideas to our own creativity, because we were not burdened with the idea of limitations and constraints at this time. 5G for us, for lack of a better term, is a wild west, and we are able to shape it to how we wanted. And because we are creating a simulation software for this project, it is extremely educational to learn how this type of process works, and why it is important to have a good grasp on the ideas that will be used in the simulation.

As for available technology with 5G, there is very little out there at the moment. This left us at a bit of a disadvantage, as we weren't able to really look at any examples of what we were trying to accomplish, but instead are creating the example for other research groups later in the line. In more specificality for our project, there is almost no simulation software for 5G software. As such, we have no basis to look at for an example for our project.

One of our main trade-offs for the project, though, is though we have a lot of unknowns and catch-up for terms of knowledge, we have the advantage of being able to do whatever we need to make the software work. As such, we get to really explore our creativity and come up with some very unique solutions that may be used later in academic projects, which would be extremely valuable to us all.

3.5 Design Analysis

Our proposed design appears to have some flaws as the existing open-source 5G simulator project/community, OpenAirInterface, is still a work in progress. We are working to get this simulator running and may need to develop it further to meet the needs of our project.

Some of what is currently working for this project, however, is being able to learn about the 5G algorithms we are going to need for this project. We have also gotten our remote system setup, so that all members can use a reliable, stable, version of Ubuntu that we will be using to run, test, and program with OAI.

Currently, we have ran into some problems with getting OAI to run by itself, as well as learning how to begin the process to integrate our chosen UAV simulator inside of OAI. As such, we have taken the current semester to start learning of the process, and get familiar with OAI and the chosen simulator. As such, we will begin implementation a bit behind schedule, but feel that it will be a much better decision, in the end, as we will have a clear grasp and understanding of both the simulators.

3.6 Development Process

We are taking an agile approach for the design of this project. We all thought that being able to take a very flexible approach to how we how we approached the design process and implementation for a very broad project description, that we would be able to handle anything that is thrown at us for acceptance criteria, and be able to quickly shift gears to other parts of the project without sacrificing quality.

Another reason for choosing agile for this project was that it was something that we were all comfortable and used to, so that we could seamlessly integrate this into our project. So far, this has been able to keep our milestones and objectives clear, as well as keeping an open line of communication for all.

3.7 Design Plan

First, we expect to be able to combine our OAI and a UAV simulator together into one large simulation software. This is so that when we begin to integrate our chosen algorithms into the simulation, it will be a large, whole software system that we can then use to test our algorithms in systems. Once this is completed, we will then attempt to write specified parts of the simulation for aerial vehicles, as this was chosen by our group as the focus point for our project. We'll know when this is finished when we can run a base simulation using the created software, thus ensuring it was built correctly.

For our modules, we will have both the OAI and UAV simulator as our main modules, but inside each of those, we will need to specialize certain interfaces inside of those modules for the simulation, such as aerial versus ground simulation, ect. At this time, we do not have a designed image for this yet, but are working on setting up the infrastructure to get us to the simulation. To simulate these modules that we will be constructing, we expect to individually test those modules in isolation, so that we do not have conflict between the modules. Once we have those constructed and tested, we will know that the modules will be working properly and we can mark them off as done.

As for our constraints, we just need to ensure that our simulation software is able to simulate aerial vehicles, as well as implement in a 5G simulation. With using the two modules explained earlier, OAI and UAV simulator, we hope that these requirements will be met, and can specialize parts of the simulation to satisfy these requirements. In regards to the use-cases to ensure that these constraints are met, we are expected to provide a small demonstration later in the semester to show that our simulator can simulate a UAV moving as one might expect, while utilizing the 5G algorithms that we will be implementing into the simulation.

4 Testing

To ensure proper functionality of our simulator we will need to produce various unit tests to verify that each module within our simulator is working correctly and integration tests to verify the system is working together the way it is supposed to. As for non-functional testing, we will test for performance factors such as runtime to ensure that the simulator is optimized and usable. Other challenges we will need to face with our simulator include, simulation of large numbers of aerial vehicles on the same 5G wireless network. For this, non-functional factors such as runtime will be very important so the simulation doesn't slow down too much.

4.1 Unit Testing

Our project consists of conducting UAV's simulations in a 5G wireless space. We need to first configure and test these two programs separately to see if they are able to function by themselves. Once the separate programs have been configured and tested we will focus on combining them together to perform simulations and record our findings.

4.2 Interface Testing

Our project consists of two separate interfaces; OAI and Paparazzi. These will be our main interfaces and we will be able to test these individually. Once these are tested and fully functional we will need to test the integrated version of these interfaces.

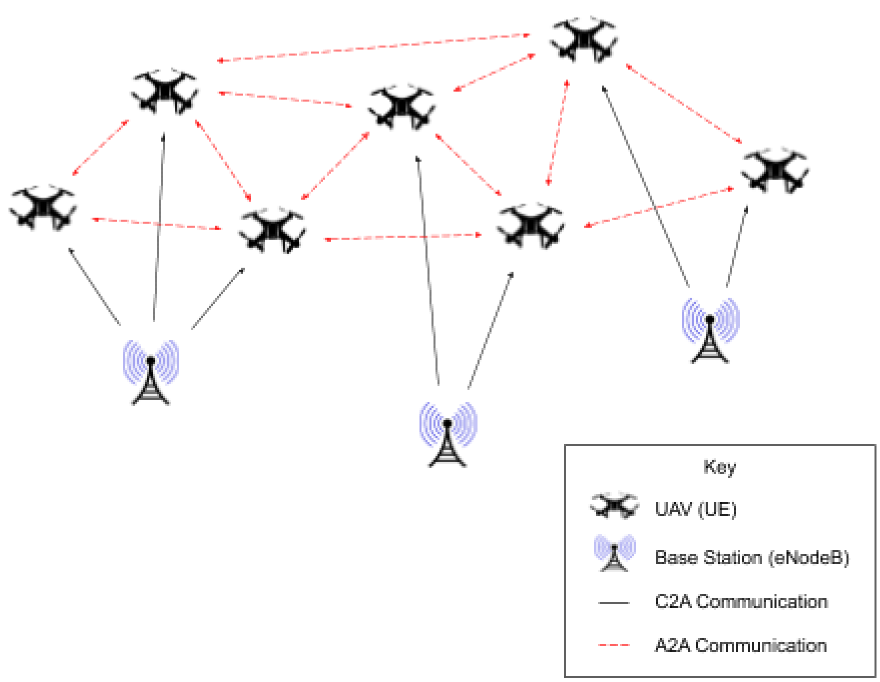
4.3 Acceptance Testing

We are working with graduate students that are also doing research on this topic. To make sure that we are meeting requirements set by our client we communicate our results, questions and concerns to the graduate students. Once we have gotten the general approval from the graduate students then we can take our end product to Dr. Zhang.

4.4 Results

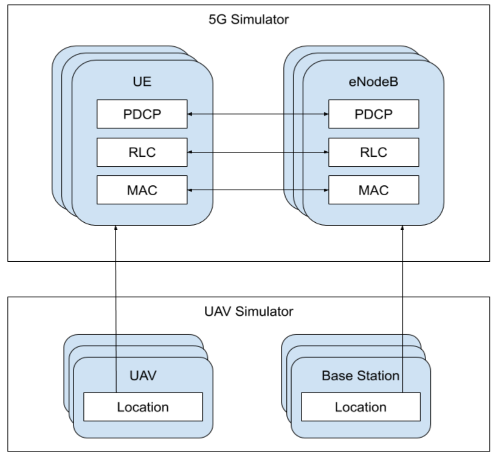
We have not run major tests for this project, as we are still configuring and understanding wireless networking and infrastructure. We are working with the members of our faculty mentor's research team to properly configure, build and run OAI. This in itself is a learning process as there are no visual manuals, directions or self-help youtube videos to guide us with OAI, as OAI is used by developers and industry professionals. However, as scholars of Iowa State we are able to use your knowledge and experience to tackle new challenges and hope to combine OAI with the UAV simulator to test and record our findings.

5 Implementation



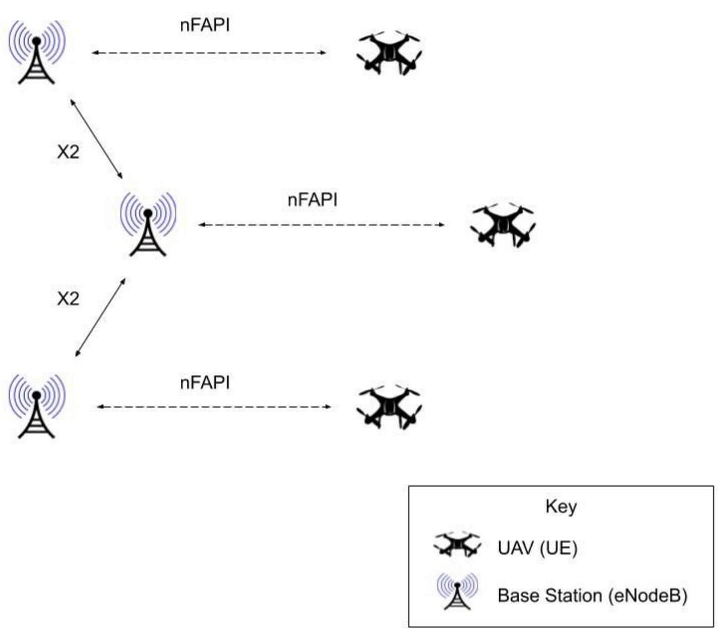
(Fig. 5: High level diagram of connections between eNB interfaces and Drone UE's)

For our implementation, we plan to integrate a UAV simulator into a 5G simulator. To do so we hope to utilize an API that allows us to extract location data from the UAVs into the 5G simulator to allow us to simulate inter drone communication. Currently we are able to simulate one UE to one eNB, but eventually we want to be able to simulate a multi cell environment with multiple eNBs with multiple UEs. We will also need to find a suitable UAV simulator that will allow us to access location information on simulated UAVs and then be able to add positions of eNB base stations onto the existing environment.

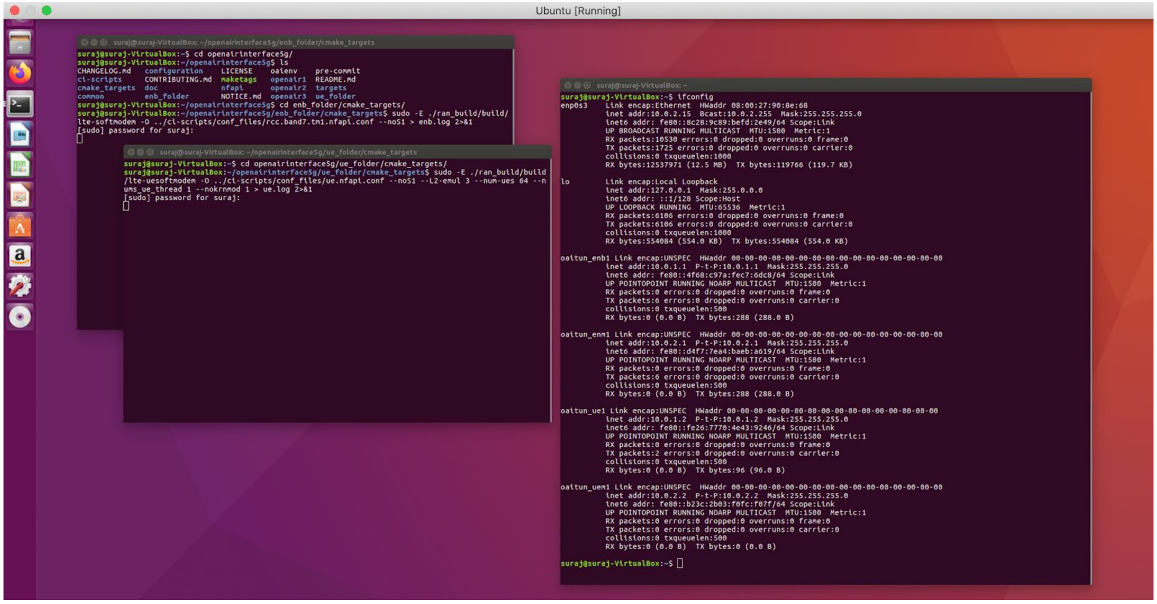


(Fig. 6: Proposed design for integrated simulator)

To simulate multiple eNB we will need to build or expand upon the X2 interface in OAI. The X2 interface is the interface that allows communication from one eNB to another. We will also need to look into the FAPI and nFAPI interfaces which are used in the version of the OAI simulator that we plan to work with. This is a simplified version that consists of only the RAN network (i.e. no S1 interface that connects to an EPC). The nFAPI interface is used to communicate between the eNB and UE in the simplified version of the simulator.

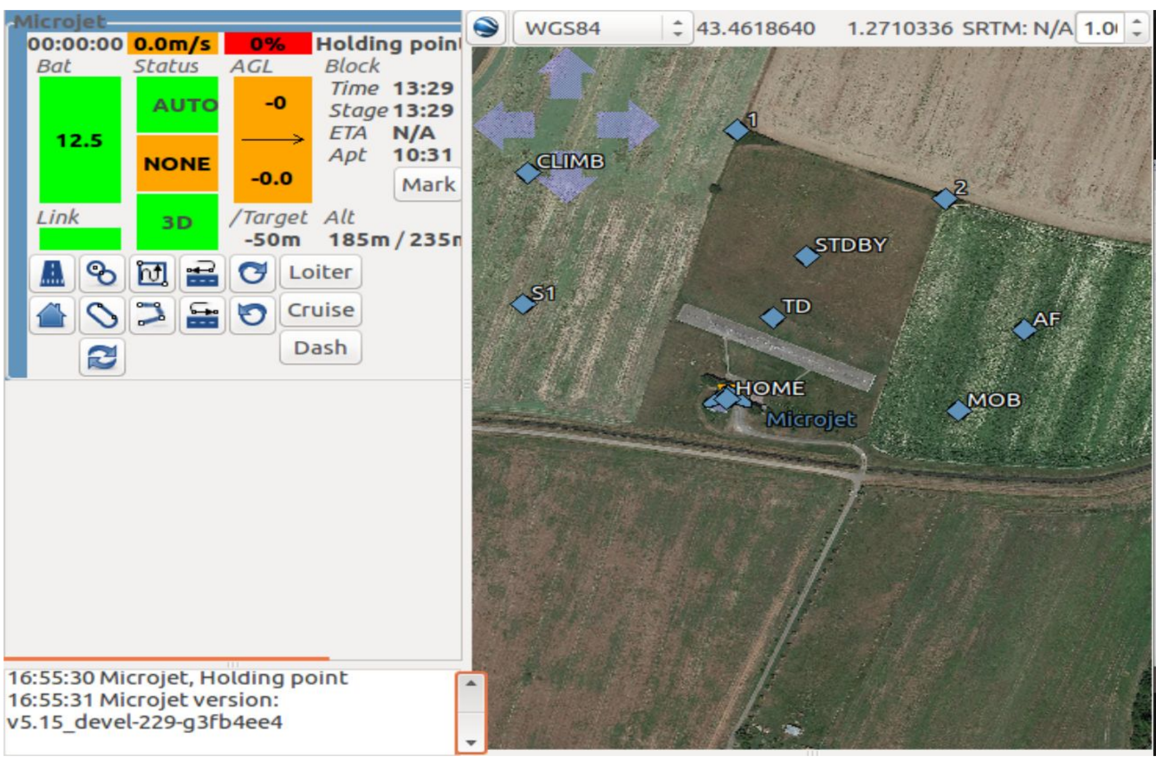


(Fig. 7: Interfaces diagram)



(Fig. 8: Simple Implementation with 1 eNB and 1 UE on Ubuntu 16.04)

Currently we are running eNB's (e Node B's) and UE's (User Equipment) for OAI on Ubuntu 16.04. We are planning to build on this by taking the coordinates given to us from our UAV simulator and then inputting the data into our UE configuration file to test the connection.



(Fig. 9: Example of basic simulation using PaparazziUAV)

So far we are experimenting with PaparazziUAV and getting experience with how the builds work. It will be important for future implementation to understand everything going on and how the simulation works.

6 Closing Material

6.1 Conclusion

Overall, we are happy with the progress that we have made so far. We have done a lot of research on the topic of 5G networking and networking algorithms. We have also been able to get familiar with the OAI and Paparazzi UAV simulators. The next steps for our project will be experimenting with how we can integrate the two simulators. This will involve continuing to work with the simulators and figure out what we need to add/change. We will also begin to experiment with networking algorithms and start to expand/design our own algorithm that will be the most effective for our project.

6.2 References

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