Drone 5G Network Performance Modeling – Sky Seer

Jung In Chang, Jong Whee Jeon, Do Hun Ji, Ryan Mondonedo, Peter Wallace

Executive Summary (Author: Ryan) — As commercial implementations of aerial drone fleets become more prevalent, there is an increasing need for beyond line of sight (LOS), autonomous operations. These would rely on communications networks, such as 5G, and would require minimal latency for precise control. Currently, there is minimal understanding of whether 5G network connectivity can support drone operations at altitudes of up to 400 feet above ground level, which is the airspace allotted to drones. To obtain a better understanding, this project will model 5G network performance at such altitudes. We propose the installation of a 5G cellphone on a quadcopter drone. The cellphone will conduct network speed tests and push the results to a cloud database. The collected data will then be used to produce the final deliverable, which will be a machine learning model of 5G network performance at the various altitudes.

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1 INTRODUCTION (AUTHOR: RYAN)

THIS project is an exploration of a future vision of small unmanned aerial vehicles (UAVs). Innovation in UAV technology has introduced the possibility of further automation by companies [1]. One such example is Prime Air, Amazon's drone, package delivery service [2].

Not every company has the resources to implement its own satellite network, such as Amazon's Project Kuiper [3]. As a result, they would rely on existing telecommunications networks for UAV connectivity and control. 5G networks are the forefront of contemporary telecommunications development, so their ability to support UAV operations is of particular interest. The main issue is there is currently insufficient understanding of 5G network connectivity at the various altitudes that UAVs could operate at because 5G networks are primarily designed to serve users at or near ground level.

Our client, AT&T Labs, is interested in more closely examining the performance of current 5G networks in the air. By doing so, AT&T Labs can learn if current infrastructure is adequate or if changes need to be made to support future UAV operations. UAVs losing connectivity during operations could potentially be catastrophic. If a UAV were to crash there could be damage to the UAV itself, damage to its payload, damage to other property, or even injury to people in the area.

This project begins with collecting 5G network performance data on the ground and at up to 400 feet above the ground, which is the maximun height the Federal Aviation Administration (FAA) allows personal UAVs to operate at. Once network performance data is collected, machine learning will be used to produce a model for the various altitudes. The modeling from this project will serve as a proof of concept for our client. They will be able to see how well 5G network performance at altitude can be predicted. Consequently, they would be better informed of how much additional research should be conducted for this particular problem, in pursuit of making a final determination on whether current 5G infrastructure would be able to sustain future UAVs.

2 CONCEPT DEVELOPMENT (AUTHOR: RYAN)

2.1 Hardware Functions and Selected Means

This project consists of an interconnected hardware-software system. The final deliverables of the project are the modeling of network performance at various altitudes and the software used for data collection. However, additional hardware is also needed to enable data collection in the first place.

To collect network performance data, network speed tests will need to be conducted. In particular, the Ookla speed test will be used since it was recommended by our client. To run the 5G network speed tests, some sort of computing hardware with 5G connectivity is necessary. We decided to use a 5G Android phone to carry out such functions and a 5G SIM card for it was provided by our client.

To collect data at altitudes up to 400 feet, we need our own UAV to carry the phone. A DJI F450 Pixhawk quadcopter drone kit will be used as it was provided by our client.

2.2 Software Functions and Selected Means

A considerable amount of data is necessary to make our machine learning models as robust as possible. To conduct the large amount of network testing, an app will be created and run on the phone. The app should be able to repeatedly run Ookla speed tests.

To conduct machine learning on the collected data later on, we need to make sure all of the data is stored and is accessible remotely. We decide to use a MySQL cloud database, which the app will push collected data to.

For the actual machine learning, Python will be used due to familiarity with it and its comprehensiveness.

2.3 Design Choices

One important decision that had to be made was what hardware would be used for data collection. We ultimately chose to go with a 5G Android phone (Samsung Galaxy A32

5G), but we initially considered using a Raspberry Pi with additional modules. The Raspberry Pi solution was abandoned because it would have resulted in a hardware payload that was too heavy for our drone to lift. Additionally, the additional modules that would be needed to connect to 5G networks would have been more expensive than just using a 5G cellphone.

Another important design choice was to create an Android app to carry out the data collection. Originally, we considered running a Python script on the Android phone through a Linux emulator. The script used the Ookla speedtest-cli, and while it successfully gathered performance data, the position data that we obtained was of the nearest network speed test server. For this project, we need the phone's actual altitude and position. Using a native Android app and the Ookla SDK would produce more accurate results for measurements of altitude and position. Also, it should have better runtime because Python is not meant to be run on an Android phone.

2.4 Engineering Requirements

The specific engineering requirements can be found in Appendix 1.

3 System Descrption

3.1 Solution (Author: Ryan)

The main goal of the project is to model 5G network performance at altitudes of up to 400 feet above the ground using machine learning. There is no existing dataset that would be applicable for this project, so before any modeling can be conducted, 5G network performance data will need to be obtained from scratch. Our data will be obtained by a custom hardware apparatus that uses custom software. Furthermore, our generated dataset will account for additional variables that could affect measured 5G network speeds. For now, we will focus on gathering data at different locations in the Boston area at different times of the day and on different days of the week.

The main hardware consists of the 5G Android phone attached to the quadcopter drone. The phone will be connected to the 5G network in the area. As the drone is flown to different altitudes, the phone will run our data collection software. The collected data is pushed to a cloud database we have set up. Finally, the saved data is imported into a Python machine learning algorithm to model 5G network upload and download speeds for the different altitudes. The overall system described here is depicted in Fig. 1.

More specifically, the data collection software will be an Android app created in React. The app will use the Ookla SDK for the network speed tests and will use the phone's built-in sensors and Android libraries and APIs for the altitude and postion coordinates. Lastly, the app connects to our SQL database so it can automatically save the collected data. The different components of the data collection software are depicted in Fig. 2.

Two other software components are a web app that will enable the team to remotely interface with the phone while collecting data and a 3D regression visualization of the model results. The web app will contain commands for executing speed tests and retrieving results. The model visualization will be part of the machine learning algorithm.

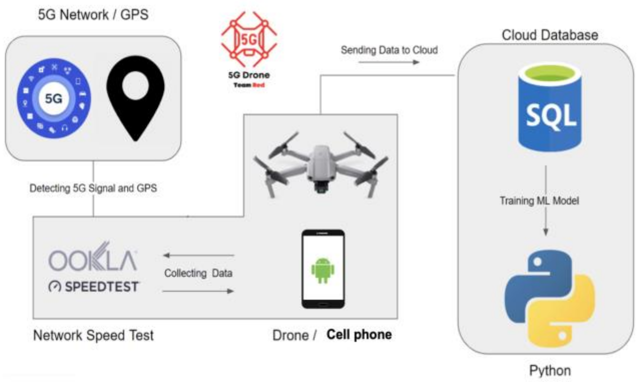

Fig. 1. Overall system diagram. This shows the interaction of the various components of the project.

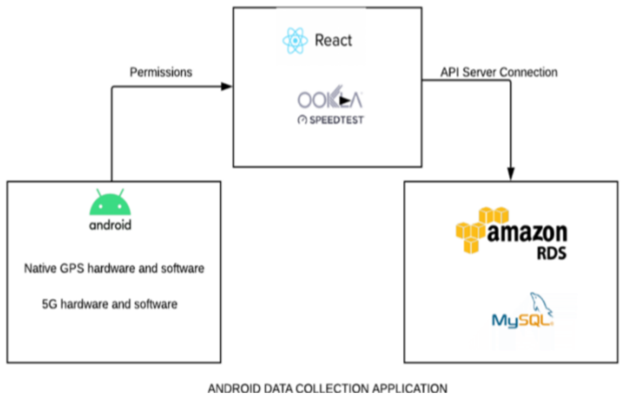

Fig. 2. System diagram for the data collection software. This shows the specific components and functions of the Android app that will run on the phone to gather and store network speed data in the database.

3.2 Data Collection Pseudocode (Author: Peter)

Pseudocode for our data collection app is as follows:

```
install mysql package
install maps package
install barometer package

while true {
network_results = Ookla.sdk.run()
gps_result = fetch_current_location(google maps api)
LATITUDE = gps_result.latitude
LONGITUDE = gps_result.longitude
DL_SPEED = network_results.download
UL_SPEED = network_results.upload
ALTITUDE = barometer.get_altitude()

database = mysql(database link)
database.connect()
Insert into database {DL_SPEED, UL_SPEED, LATITUDE, LONGITUDE, ALTITUDE} {%f, %f, %f, %f, %f, %f} (DL_SPEED, UL_SPEED, LATITUDE, LONGITUDE, ALTITUDE)
database.commit()
}
```

3.3 Machine Learning Pseudocode (Author: Jung In)

We have not been able to collect actual data yet, but we have a preliminary machine learning algorithm that was developed from sample data from Kaggle. Pseudocode is as follows:

```
install pandas package
install numpy package
install sklearn multi-output regressor

get file path of sample dataset
read the dataset using pandas dataframe
drop unused columns ['country', 'date']
set X (input) ['country code', 'distance miles', 'total tests']
set Y (output) ['upload kbps', 'download kbps']
split train and test dataset
convert X and y to numpy matrix
fit multi-output regressor model to X_train and y_train
test the sample dataset to get accuracy
plot the model result, comparing actual and predicted speed
```

4 FIRST SEMESTER PROGRESS

The end result of the project is an interdependent system, but it was possible to work on most of the different components in parallel. As different segments get completed, they can be brought together.

4.1 Drone (Author: Jong Whee)

There was initial difficulty because it was unknown whether we would be able to obtain a drone that met our needs given our budget. However, our client later provided a drone kit. The drone was received at the end of November and construction is ongoing.

4.2 Computing Hardware (Author: Ryan)

A final decision to use a 5G cellphone as the computing hardware for data collection was accomplished. The two main options were using a 5G phone or a Raspberry Pi with 5G connectivity (5G modem card, 5G network module). To decide which path to choose, a quantitative analysis of the overall cost and weight was carried out. It was found that using a 5G phone would be cheaper and lighter overall. The weight of the hardware we chose was of particular importance because our drone has a payload limit. The analysis showed that using a Raspberry Pi would be very close to the weight limit while using a phone was less risky since there was more leeway.

In addition, it was decided what specific phone we are using, the phone was purchased, and the phone was obtained. iPhones were out of the question because 5G capability was only in pricer models. An additional analysis of network compatibility for the cheaper spectrum of 5G Android phones resulted in choosing the Samsung Galaxy A32 5G.

4.3 5G SIM Card (Author: Jong Whee)

Another major concern for the project was how we were going to collect enough data to build our training dataset. Whether we used a 5G phone or a Raspberry Pi, the hardware would need to connect to 5G networks through a SIM card. We would need an unthrottled and unlimited SIM card for this project. Throttled network speeds would jeopardize the accuracy of our collected data and a non unlimited SIM card could result in incredible costs for data usage when running many speed tests. Fortunately, it was arranged for the client to provide a SIM card. We are currently waiting for the SIM card to arrive.

4.4 Phone Mount (Author: Jong Whee)

Although the drone construction has yet to be completed, it was possible to begin designing how the phone could be attached. A set of design requirements and guidelines were laid out. Additionally, a preliminary concept, where a magnetic phone mount would be used, was developed.

4.5 FAA Drone Regulations (Author: Ryan)

Additional preparation for operating the drone to collect data was required. The FAA requires recreational and educational drone users to complete The Recreational UAS Safety Test (TRUST) and obtain a certificate. Also, the drone user must be able to provide proof to the FAA or law enforcement upon request [4]. The TRUST certificate was obtained as no team members have had any prior drone operating experience. Once the drone is constructed, it will also need to be registered with the FAA.

4.6 Data Collection (Author: Peter)

The data collection software was initially developed in Python using the speedtest-cli, pymysql, and geopy. A Python script was run on the 5G phone, but after testing it was decided that it would be better to use an Android app. The location data obtained was for the nearest network test server rather than the phone, which would not be viable for the project. Additionally, multithreading was attempted to speed up the data collection process. However, a significant drop in network performance was observed compared to a single test run.

Implementing an Android app will be the next iteration of the data collection software. The app will need to use the Ookla SDK. To get access to the SDK at no charge, it was necessary to contact Ookla and complete a contract. The contract has been signed and returned to Ookla and Ookla has let us know they are working through the final steps to provide us their SDK.

4.7 Database Management (Author: Do Hun)

The database for the project was initially implemented as a MySQL database in a local host device. This was found to be restrictive since connections to the database had to have the same IP address as the local device.

The next iteration was creating a MySQL database using the AWS Relational Database Service (RDS). This was an improved design because it enabled connections from any IP address, which meant that the data collection device could connect to the database from anywhere.

The database currently consists of seven columns: id, download speed, upload speed, distance to best server, latitude, longitude, and altitude. Download speed, upload speed, and distance to best server are what are currently obtained from the data collection script. Latitude, longitude, and altitude still come from IP address and will be implemented through the Android app.

4.8 Machine Learning (Author: Jung In)

As mentioned, actual data could not yet be collected, so a sample dataset from Kaggle was used to make the prototype of the machine learning algorithm. The sample data included items that are not applicable to this project, such as country code and total tests. Additionally, latitude, longitude, and altitude will be used for the project but were not part of the sample data.

The first model that was built used one regressor for multiple outputs. This was not very successful and resulted in 0.2% accuracy in testing. A second approach with a multi-output regressor from Scikit-learn was used. This worked much better and achieved over 88% accuracy.

5 Technical Plan

5.1 Drone (Author: Jong Whee)

Task 1. Drone Construction.
We now have the parts from the F450 Quadcopter Pixhawk kit, which includes the frame, 4 propellers, 4 motors, flight controller, GPS receiver, and battery. An operational drone will be constructed so that aerial data collection can occur. *Lead: Ryan Mondonedo; Assisting: Jong Whee Jeon.*

Task 2. Drone Regulations.
The drone will be registered with the FAA once it is complete. Additionally, the rest of the team will be instructed on what drone regulations to be aware of when collecting data. *Lead: Ryan Mondonedo.*

5.2 Additional Hardware (Author: Jong Whee)

Task 1. Phone Attachment.
An apparatus to secure the phone to the drone during flight will be designed and tested. *Lead: Jong Whee Jeon; Assisting: Ryan Mondonedo.*

Task 2. Electronics Protection.
Additonal protection and insulation for the electronics on the drone will be designed and tested. Stronger wind and colder temperatures higher in the sky could affect the battery performance of the phone and drone. *Lead: Jong Whee Jeon; Assisting: Ryan Mondonedo.*

5.3 Data Collection (Author: Peter)

Task 1. Ookla SDK Implementation.
An Android app capable of running network speed tests and storing the results will be implemented using the Ookla SDK. The app will be tested alongside the Ookla speed test web app to measure runtime performance and result accuracy. *Lead: Peter Wallace; Assisting: Do Hun Ji.*

Task 2. Altitude and Position Data Collection.
The app will be designed to also gather altitude and geolocation data. GPS and altimeter data shall be collected using the Google Maps API and the Barometer npm package, respectively. The app will store these data points in the database. These functionalities shall be tested alongside the Google Maps app and the Current Altitude app from Hearn Apps, LLC to measure result accuracy. *Lead: Do Hun Ji; Assisting: Peter Wallace.*

Task 3. Data Collection Plan.
A plan of where and when data can be collected by our drone platform will be developed. The plan will incorporate various locations in the Boston area. *Lead: Ryan Mondonedo.*

Task 4. Data Collection for Training Dataset.
The produced data collection plan will be carried out to actually obtain our training data. *Lead: Ryan Mondonedo; Assisting: Jong Whee Jeon.*

5.4 Machine Learning (Author: Jung In)

Task 1. Deep Learning Implementation.
Implement deep learning algorithms using Tensorflow Keras to improve model accuracy and F1 score. Convolutional Neural Networks will be used for dense layers with ADAM as the optimizer and ReLU as the activation function. The model must take multiple inputs, such as latitude, longitude, and altitude. *Lead: Jung In Chang; Assisting: Peter Wallace, Do Hun Ji.*

Task 2. Model Visualization.
The current visualization only depicts a linear relationship between the predicted and actual network speeds. A 3D regression plane will be designed to show the relationship between inputs (latitude, longitude, altitude) and outputs (upload and download speeds). The regression model will be an inclined plane instead of a line since the target labels are split into upload and download speed. *Lead: Jung In Chang; Assisting: Peter Wallace, Do Hun Ji.*

Task 3. Model Maintenance.
Even though the sample data that was found has a similar structure to what our project will use in the future, additional steps are needed to optimize prediction accuracy. The data categories will be updated to include latitude, longitude, and altitude. Also, data pre-processing with normalization and zero paddings will be conducted to prevent errors encountered in the initial machine learning implementation. Overall, additional trial and error will be necessary to obtain the best model possible. *Lead: Jung In Chang; Assisting: Do Hun Ji.*

5.5 User Interface (Author: Do Hun)

Task 1. User Interactive Web App.
A React web app for data visualization and control of data collection will be developed. The app will display synchronous updates on the current GPS coordinates and altitude of the data collection phone. The user will be able to input commands for the data collection operation, such as executing a network speed test. The app will display the result of the test as it saves it to the database. Also, it will include the ability to retrieve the machine learning prediction of network performance at a given altitude and set of GPS coordinates. *Lead: Do Hun Ji; Assisting: Peter Wallace, Jung In Chang.*

Task 2. Remote Connection.
A remote connection between the data collecting device and controlling device will be established to enable

remote control. One planned approach is socket programming, and another is to transfer commands over the constructed database. *Lead: Do Hun Ji; Assisting: Peter Wallace, Jung In Chang.*

6 Budget Estimate (Author: Ryan)

Table 1 below shows the items that are needed for this project along with their respective costs. As can be seen in the table, the largest item will be the 5G cellphone. It will take up a large portion of our $500 reimbursable limit, but it was the cheapest option that met the project needs. A commercial, off-the-shelf phone mount is the option we are currently considering for attaching the phone to the drone and purchasing a spare LiPo battery for the drone was recommended to us by our client. The rest of the project components is software.

TABLE 1
Project Budget

Item	Description	Cost
1	5G Android phone	$297.49
2	Magnetic phone mount	$10
3	Spare LiPo Battery	$68
	Total Cost	$375.49

Table 2 below shows the items that were provided by our client and are not considered part of the project budget. As can be seen, the drone components have a considerable cost and would have been difficult to fit into our budget if they were not provided to us.

TABLE 2
Items Provided by Client

Item	Description	Cost
1	DJI F450 Quadcopter Pixhawk Drone Kit	$230
2	RC Transmitter and Receiver	$200
3	LiPo Battery	$68
4	LiPo Battery Charger	$40
5	AT&T 5G SIM Card	N/A
	Total Cost	$538

7 Attachments

7.1 Appendix 1 – Engineering Requirements (Author: Ryan)

This section contains the engineering requirements for each of the different aspects of the project.

Hardware

1. The computing hardware can connect to 5G networks.
2. The drone can fly up to 400 feet with all attached hardware (attached hardware weighs no more than 1 pound).
3. The drone must be able to fly for at least 10 minutes on a full charge (within minus 10 seconds acceptable).
4. Phone mount secures phone to the drone as it flies.

Data Collection

1. Measure 5G network upload and download speeds to at least 1 decimal place.
2. Measure altitude within 10 feet.
3. Measure GPS coordinates to at least 3 decimal places.

Data Storage

1. Database can store all of the collected altitude, GPS position, and 5G network performance data (upload and download speeds).
2. Stored data must be importable into Python for machine learning.

Modeling

1. Machine learning algorithm must produce predictions of 5G network upload and download speed at altitudes of up to 400 feet above the ground.
2. Algorithm must have at least 80% test accuracy (less than 20% test error).

Cost

1. The total cost of all of the components of the project must not exceed $1000.

7.2 Appendix 2 – Gantt Chart (Author: Jung In)

The Gantt Chart for the project is shown on the following page.

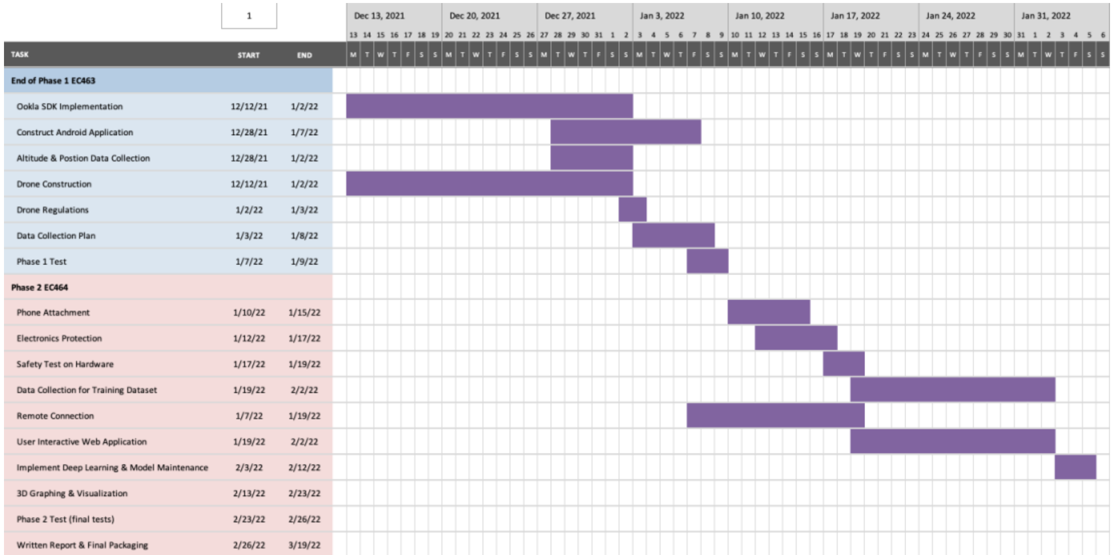

Fig. 3. Gantt Chart showing the present up to the week of January 31, 2022.

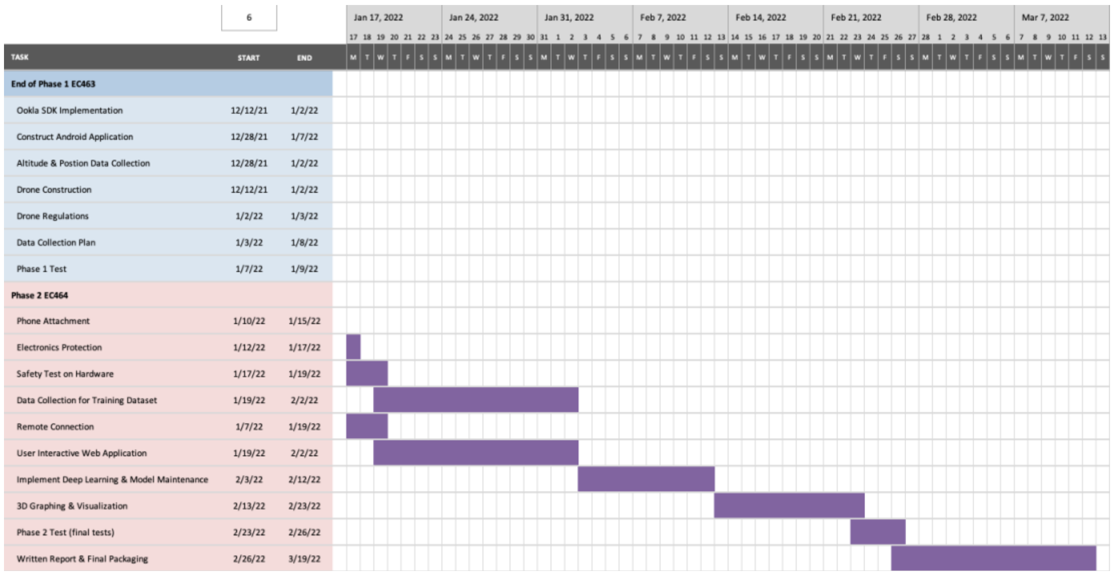

Fig. 4. Gantt Chart showing up to the projected end of the project.

7.3 Appendix 3 – References

[1] P. Cohn, A. Green, M. Langstaff, and M. Roller. "Commercial drones are here: The future of unmanned aerial systems." Mckinsey.com. https://www.mckinsey.com/industries/travel-logistics-and-infrastructure/our-insights/commercial-drones-are-here-the-future-of-unmanned-aerial-systems (accessed Oct. 17, 2021).

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