Energy Awareness in Flying Base Stations Trajectory Optimization

Introduction

Unmanned Aerial Vehicles, also known as UAVs, are drones which have many uses such as cargo delivery, surveillance, agriculture. However, they also have another use which is extremely helpful, and it is that they can extend the range of cell towers and/or increase the speed of the network.

UAVs have many use cases. A cell tower that is malfunctioning and needs to be repaired is one such instance where UAVs can be used. UAVs are also used when climate catastrophes such as earthquakes or landslides occur, where building infrastructures are not physically possible nor are they economically viable.
In densely populated areas, such as concerts, sport events, or any other densely populated area where there will be more demand for data usage, UAVs can also increase the network speed and cater to the high demand in those areas.

However, the problem is that these UAV-BSs can only be in the air for a limited amount of time before they return to their depot to charge again. The typical flying time for a flying base station is less than an hour. Besides, these drones cause significant noise pollution, especially when there are multiple of them in the same region. When hovering, the noise can reach 85dB, which is around the same amount of noise a leaf blower, or a lawn mower makes. Fortunately, these problems can be solved by attaching effectors which can grasp onto urban structures such as lamp posts in an energy neutral manner. This could increase the duration of service from less than an hour to several hours.

Robotics airborne base stations, or commonly referred to as RABS, are a modified version of the standard UAV. Aside from operating silently, RABS also has another advantage which really distinguishes it from ABS. It is the fact that it is weatherproof, specifically rainproof. Hovering during rainfall is incredibly difficult for drones to perform, regardless of the weight of the drone. RABS solves this problem permanently since it uses its grapplers. From previous research. The average energy consumption of a normal ABS (4kg) while hovering is 320J/s, whereas in that same time frame, a RABS which is grasping on to an object will only consume 15J/s, increasing the total service time by about 35-fold.

In this project, I will investigate the factors that affect the energy consumption of UAV-BS, and how efficient robotic airborne base stations (RABS) are from standard hovering. The problem I intend to solve is finding the optimum path trajectory of the base station depending on the number of nodes, the distance between the nodes, and the service time in each of the node regions. I will also incorporate external factors as well, such as wind, rain, and other obstacles.

Gannt Chart from November-April

Tasks	Nov			Dec			Jan			Feb			Mar			Apr		
Deeper Research (Derive Necessary Equations)																		
Accumulate all software and libraries required.																		
Simulation in MATLAB																		
Obtaining Data & Analysis																		
Simulation II ML (MATLAB)																		
Simulation III (Python)																		
Final Analysis and Conclusion																		
Drafting Project Report																		
Final Corrections																		
Video Presentation																		

Objectives

The code will be written in MATLAB with the help of 2-opt algorithms. 2-opt algorithms are useful in solving trajectory problems. The most famous one is the travelling salesman problem, where the salesman must find the optimum path to different locations before the salesman returns to the starting point. This problem can be used in other situations as well, such as the optimum path for a bus when dropping students, deliveries by courier companies and of course, drones.

The full simulation will be implemented through MATLAB. The environment will start from the most basic case: one node. This will ensure that the environment is running correctly and that all the calculations are correct. Then the RABS factor will be added and compared to a nominal ABS. After this, the problem will get progressively more complex to calculate as there will be more nodes added and the distance between those nodes will be a determining factor as well.

I will also go beyond the scope and attempt to incorporate machine learning as well. This will be in the lines of genetic algorithms as they are one of the best when it comes to solving optimisation problems. The overview of implementing the genetic algorithm is as follows:

i) Creating initial population – There will be multiple species (in this case the drones) which will start from the depot. All

ii) Initialise the fitness variable – This is relatively straightforward. The drone with the least amount of energy consumed after returning to the depot will receive the highest fitness score.

iii) Mutations – The best species from the current generation will be mutated randomly and will become the population for the next generation

This process will repeat for multiple generations until the energy consumption of the drone has reached an optimum result. With this training, the fittest drone will then be validated with a new random path.

All the steps done so far are in 2-Dimensional. If these simulations are successful, then I will move on to the 3-D version of this model where there will be more factors included. This includes obstacles and changes in weather patterns.

In summary, here are the tests I will perform and the factors I will add as the project progresses:

<table>
<tr><th>No.\Factor</th><th>No. of Nodes</th><th>Optimisation Algorithm</th><th>ABS</th><th>RABS</th><th>Wind</th><th>Rain</th></tr>
<tr><td>1</td><td rowspan="3">1-5</td><td>2-Opt</td><td colspan="2">Yes</td><td>No</td><td>No</td></tr>
<tr><td>2</td><td>2-Opt</td><td colspan="2">Yes</td><td>Yes</td><td>No</td></tr>
<tr><td>3</td><td>2-Opt</td><td colspan="2">Yes</td><td>Yes</td><td>Yes</td></tr>
<tr><td>4</td><td>5+</td><td>2-Opt</td><td colspan="2">Yes</td><td>Yes</td><td>Yes</td></tr>
<tr><td>5</td><td>2-5</td><td>ML</td><td colspan="2">Yes</td><td>No</td><td>No</td></tr>
<tr><td>6</td><td>2-5</td><td>ML</td><td colspan="2">Yes</td><td>Yes</td><td>Yes</td></tr>
</table>

**If I have to add more factors, I will update the documentation in the final report*

The results from the ML model to the 2-Opt model will be compared
All simulations will be recorded and will be available in the final report in the appendix.
I will also attempt to convert the code into Python language if time allows, because this will be universally accepted and easier to work with.

Learning Outcomes

I feel that this project meets the learning outcomes and goes beyond the scope of because it has everything required for industrial and professional engineering skills. From research to running the code to collecting data. The project that has been given to me will definitely help me understand and come up with a solution which will be extremely beneficial for society in general as it not only caters to the demand of the general public, but also does it in a sustainable manner that follows the esg guidelines.

Risk Management, Ethics, and GDPR

Since this project is simulation based, most of the work will be done on my laptop. Therefore, I must adhere to all the health and safety procedures. These include:

i) Correct posture
ii) Sufficient lighting to prevent any vision problems.
iii) Avoid sitting for two long and stretch occasionally.

Risk Register

This table will identify the common project risks and how they will be dealt with

No.	Risk Description	Likelihood of occurrence	Impact if risk occurs	Mitigating Action
1	Cannot simulate	Low	High	Try different libraries to simulate the environment
2	Erratic/Inaccurate results with 2-Opt	Medium	High	Try running the simulation on different devices.
3	Cannot arrive at a conclusion. (Insufficient data)	Low	Medium	Come up with more external factors to distinguish the result and come up with more tangible results
4	Inaccurate results with Machine Learning model	High	Low-Medium	Will try another algorithm other than genetic algorithms. Could try regret minimization.
5	Converting MATLAB code into Python	Low	Low	NA

The General Data Protection Regulation (GDPR) is a regulation regarding data protection and privacy in the EU region. Fortunately, GDPR will not be an issue as I am not using other peoples' data for this project. All the software and algorithms I am using are publicly available on the internet.

Ethics:

Drone laws are generally strict all over the world. There are many laws that have restricted drone usage. In fact, almost all countries in the MENA (Middle East/North Africa) region have either banned UAV usage or have made it close to impossible to fly drones without getting the required licence. There are multiple reasons to this, such as:

i) Instability of the political climate of the country. Drones are seen as a threat in such countries.
ii) Security and surveillance reasons

iii) Wildlife protection

Drone laws in the UK are strict as well. You must have a licence to operate a drone in London and this can only be obtained from the Civil Aviation Authority (CAA). Drones can’t be flown over crowded areas. Unfortunately, this happens to be the primary use case for the UAV. The drone must not be over 500g. Most ABSs weigh a minimum of 4kg. The CAA also mentions that when operating, the drone must exceed the height of 120m, whereas most UAVs performing communication service operate higher than this. Regarding weather conditions, the CAA vaguely mentions not to fly the UAV if the weather conditions do not permit but does not give the exact speed of the wind or amount of rainfall that is safe. All these factors restrict the usage of UAVs not just in the UK but in the EU region as well. Therefore, this simulation cannot be conducted in real life UK unless the UAV operator has a special permit to use the UAV.

Health and Safety:

COVID-19 is not fully eradicated yet, and it is unlikely that it ever will. Although the symptoms of the more recent mutations of COVID-19 are milder this does not mean that the precautions can be lifted. That being said, the circumstances of COVID-19 do not affect the progress of this project since this project is fully simulation based.

To avoid data loss or data corruption of the MATLAB code. I will regularly backup all my progress to the cloud until the project has been submitted. I shall also upload the project files to the public platform GITHUB, so that anybody can publicly access it.

References & Citations:

UAV Communications for 5G and Beyond: Recent Advances and Future Trends
By Bin Li, Zesong Fei, and Yan Zhang, IEEE

https://arxiv.org/pdf/1901.06637.pdf

Airbone Urban Microcells with Grasping End Effectors: A Game Changer for 6G Networks?
By Vasilis Friderikos, King’s College London

https://arxiv.org/pdf/2105.09230.pdf

Drone Laws in the UK Region:
https://register-drones.caa.co.uk/drone-code/where-you-can-fly