Juggling Drones: Distributed Drone Port Approach to Public Drone Services

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Abstract

Topics related to drones are currently a hot topic among industries and academics because of their foreseen use-cases e.g disaster relief, remote search and rescue. However once drones are readily available for regular users who do not hold a pilot license, air traffic congestion and designation of safe landing areas is expected to become a challenging factor to manage. To reduce capital expenditure, we propose a system where the total number of charging stations available is less than total number of drones, hence the term juggling. A juggler must throw and catch balls in the air at the same time with two hands. Our done ports can be considered the hands with charging capabilities available to charge the drone. Our goal is to maximize the consecutive cycles of drone juggling hence minimize service interruption.

1. Introduction

Drones are becoming a hot topic in research due to their potential use cases such as first response for major disasters [1]. While, companies are offering distributed rental systems including assets like bicycles and cars, there is likely to be a system for drones in the near future too. Unlike cars or bikes drones come with their own unique challenges including, providing a safe designated area. Furthermore, in regards to the location, drone ports are expected to be small stations located on rooftops in urban areas and placed in remote areas near isolated areas such as mountains. Since there is a greater safety risk associated with drones in populated areas, expensive infrastructure is likely required. Therefore, in this paper we propose a system to allow shared drone ports in a way that is similar to juggling to reduce cost. Our proposal will provide the optimal solution to maximize the number of cycles before an interruption occurs and allow developers to disregard the initial and final location of drones completing a task.

2. Related Works

Zhang et al. (2018) considered a UAV as a tool to extend cellular coverage and alleviate communicate resource bottle necks at the edge of the network [2]. However, their system model ignores the initial and final location of the drone completing a task. This raises the question how far can the drone fly from its start location to the task and then back to a designated landing area. Kurup et al. (2015) proposed a system to sense radio-active matter in the atmosphere with drones [3]. Their objective is to minimize the distance travelled by each

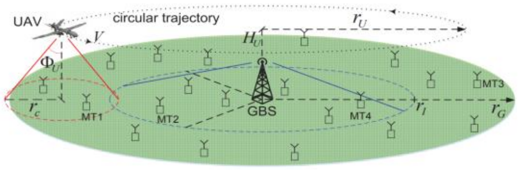


Fig. 1: UAV-aided cellular offloading.

drone. The use of UAVs in dirty situations, such as radioactive contamination, was documented after the Fukushima reactor damage [4].

3. System Model and Problem Formulation

Our goal is to tune the trade-off between the probability of a service interruption and drone ports capable of charging drones. For our system model we consider a set of drones denoted as $D = \{d_1, d_2, \dots, d_n\}$, a set of Drone Ports denoted as $P = \{p_1, p_2, \dots, p_n\}$, a set of tasks denoted as $T = \{t_1, t_2, \dots, t_n\}$ and a set of base stations denoted as $B = \{b_1, b_2, \dots, b_o\}$. The drone has three possible states which include, charging, flying to a task, completing a task and finally transmitting data to a nearby base station b.

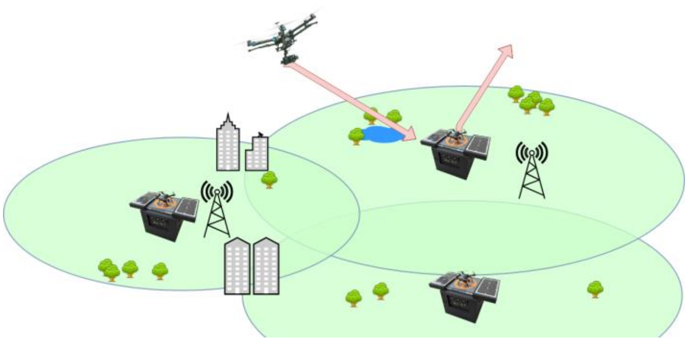


Figure 1 Juggling Act, charging drones must take off before another drone can land

Each drone d has its own energy capacity that is denoted as E = {e_1, e_2, …, e_q} Therefore, we will use e to record the current energy state of each drone. Each state excluding charging all tax the battery capacity and will be recorded by subtracting the energy consumption from the drone's. capacity. The energy by performing a task is subtracted from the drone capacity and the energy consumed by flying is denoted as gamma is subtracted

$$p_{d,s+1} = p_{d,s} - \sum_{j \in t_d} p_t - \sum_{j \in t_d} ||v^*||\gamma$$

Each task t has its own energy resource requirement to complete the task denoted as t_p. Tasks may be completed from a distance d_n creating a circular area where the drone has to enter to complete the task. This is possible since tasks such as taking images can be completed from different angles while still satisfying the request.

The access point b_o must be available to send service requests to drones. Also receive completed task data for offloading and returning data to users. We use Shannon's law to measure energy consumption and throughput.

$$r_{d,b} = W \log_2 \frac{p_d p_t}{||v_{d,t}||}$$

Drone port p is responsible for charging drones when their battery is almost depleted. Once the drone's energy is less than a threshold denoted as *L* the drone must return to the nearest drone port to be recharge. Energy is consumed while flying to and from the task, and when transmitting data to the cellular network, these may vary depending on the state of the environment. The location of these drone ports will be uniformly placed in the simulation environment and also clustered to simulate a remote and urban area. There is always equal or less drone ports than drones to reduce infrastructure cost.

Our algorithm we propose is called the drone juggler due to its behavior to juggle drones without sufficient drone ports to charge or allow drones to wait on the ground.

Algorithm 1 Drone Juggler	
Input:	Required energy from each task, Location of drone ports, location of drones, location of task, energy level of each drone
0:	**One drone is initialize in the air**
1:	**For each drone:**
2:	Assign drone to task so that energy consumed is minimized.
3:	Complete task
4:	**End for each**
5:	Central controller sends signal to drone with max power remaining to stay in the air.
6:	Drones fly to drone port with min distance and begin charging at station.
7:	**New round of tasks**
8:	Charged drones fly to complete task
9:	Drone in air lands for charging.
10:	**If drone is unable to return to base, service interruption occurs**

4. Evaluation

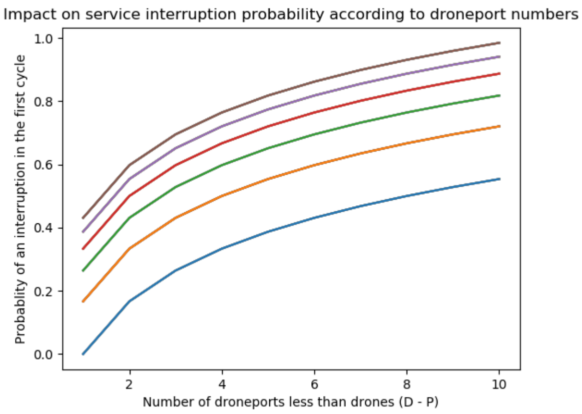
The arrival rate of tasks can be modeled as a random process. We use a Poisson process with a mean arrival rate of 1. One assumption for tasks is that they must appear in a drone's coverage area. Drones will begin at charging station with at least one drone initiated in the air due to the shortage of drone ports. Before charging, drones must be able to return back to their drone port in order to offload any data they may have gathered from the completed task. The task must be within the drone's coverage. The distance between the drone and task is calculated using co-ordinates x, y belonging to the drone and task with the Euclidean distance equation. If the distance between them is less than the threshold theta, the tasks I s assign to drone d. A charging station must be available before the drone is able to land

$$||d|| = \sqrt{(x_d - x_t)^2 + (y_d - y_t)^2 + H^2}.$$

$$a(||\mathbf{d}||) = \begin{cases} 1 & for \quad 0 \geq ||d|| < \theta \\ 0 & for \quad ||d|| \geq \theta \end{cases}$$

The simulation is conducted in Python using CVXPY library. We consider a range of drones between 1 and 10. Furthermore a range of 1 to 10 tasks and finally a range of 1 to 10 drone ports. The x axis below(D–P) denotes the difference in number of drone ports and drones. Furthermore, the transmission must be fixed so that the signal can be transmitted with a minimum distance of the maximum drone threshold to remove any

We will also look at the effect of placing drone ports near base on purpose to see if there is a reduction in cost for drones. Each simulation is interrupted when a collision between two drones requesting to charge occur or when any given drone's energy is less than a given *L*. Arrival rate, flight energy and task energy are kept constant during the simulation.



Each colored line represents the relative distance between drones and tasks. From the blue line the average distance is multiplied by 1. Each line above the blue line represents the relative average distance multiplied in the order of (2x, 3x, 4x, 5x). The results show that the average distance between drone ports and tasks has a large impact on the probability that the first cycle is interrupted due to lack of charging stations. Furthermore, increasing the number of charging stations also increases the probability of a service outage.

5. Conclusion

Indeed, distributed drone ports are the future once policies are in place to support the use of autonomous drones. Our algorithm gives way to optimize the future placement of drone ports as well as number of drone ports for populated and remote areas bringing us one step closer to a true realization of autonomous drone use. Our next goal is to implement a real system applying our algorithm with open source software such as Adrudrone between the controller and drone to transmit the request requirements in real time.

6. Acknowledgement

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