Poster Abstract: Landing-Type Aware Multi-Drone Route Generation for Last-Mile Delivery Service

JiHyun Kwon BaekGyu Kim
Dept. of Electrical Engineering and Computer Science
DGIST
Daegu, South Korea
{jihyun.kwon, bkim}@dgist.ac.kr

Yi-Ying Chen Chung-Wei Lin
Dept. of Computer Science and Information Engineering
National Taiwan University
Taipei, Taiwan
{r12944016, cwlin}@csie.ntu.edu.tw

***Abstract*—We consider the problem of generating delivery routes for multiple drones in the last-mile delivery service. In particular, the landing type—how a parcel is to be dropped off from a drone—is explicitly modeled in terms of the landing area and the landing time, which was not considered in other drone delivery works. A Mixed Integer Linear Programming (MILP) problem is formulated to optimize the delivery route for each drone by minimizing the total delivery completion time. Our preliminary result shows that landing types affect the total delivery completion time significantly, even with a small number of drones. Therefore, it is necessary to explicitly consider the characteristics of landing types for more realistic delivery route generation of a large number of drones.**

***Index Terms*—Drone delivery, Route Planning, Landing type, Mixed Integer Linear Programming (MILP)**

I. Introduction

A last-mile delivery service transports parcels from the local delivery hub to the end customer's location. Drones, which can fly over the air, have gained significant attention to overcome the limitations of ground transportation [1]. However, drones typically have limited battery and loading capacity, so minimizing the delivery completion time—the time that elapses from departure and returns to the hub after completing the delivery—is essential.

Among many features, the landing type is one notable criterion for categorizing the characteristics of delivery drones. More specifically, a landing type determines how a parcel is to be dropped, as illustrated in Fig. 1; a drone touches the ground (Type 1) or releases a rope for a parcel to reach the ground (Type 2) or drops a parcel from the air (Type 3). A single drone should exclusively occupy the drop-off location at a time to avoid collisions, so the landing type affects how large and long the area should be occupied.

We argue that such spatial-temporal aspects of the landing type affect the delivery complete time significantly, especially when many drones deliver parcels simultaneously. Therefore, it is necessary to coordinate the delivery of many drones considering landing type to reduce the overall delivery completion time. Previously, research on finding the optimal delivery route in a multi-drone-based environment was significantly conducted [2] [3]. However, research on optimal delivery routes that reflect differences according to landing type has not yet existed. Our goal is to generate routes of multiple drones to minimize the delivery completion time, considering the landing type explicitly.

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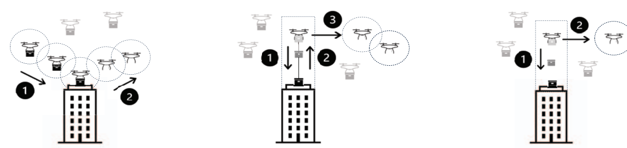

(a) Type 1 (b) Type 2 (c) Type 3

(d) Type 1 - Amazon (e) Type 2 - Flirtey (f) Type 3 - Amazon

Fig. 1: Drone Landing Type

II. Poster Description: Approach and Preliminary Result

We surveyed commercial delivery drones to categorize landing types, including DHL, Amazon, Matternet, Pablo Air, Flytrex, Flirtey, Zipline, Alphabet Inc., and Wingcopter. Fig. 1 illustrates the three categories of landing types. A *landing space* indicates how large the area (in the air) should be exclusively occupied until the drop-off is finished; a *landing time* indicates how long the space should be occupied. Such spatial (landing space) and temporal (landing time) aspects differ in each landing type, and here is the summary of the landing types illustrated in Fig. 1.

Landing Type 1: A drone directly touches down the ground to drop off a parcel. Since the drone does not need to hover in the air, the landing space size is smaller than that of other types. Therefore, other drones can pass through or hover through these unoccupied spaces. The landing time of Type 1 is from when a drone touches down to when it leaves the drop-off location (*i.e.,* a parcel is expected to be released between the two moments).

Landing Type 2: A drone hovers over the drop-off location and uses a rope to slowly move down a parcel from the hovering point. The landing area, illustrated as a dotted rectangle in Fig. 1 (b) is the entire vertical space from the drop-off location to the hovering point; a rope is expected to move up and down within this area. This implies that if another drone is to deliver a parcel to the same location simultaneously, it needs to hover outside the landing area until the drone that occupied the landing space first finishes the drop-off. The landing time

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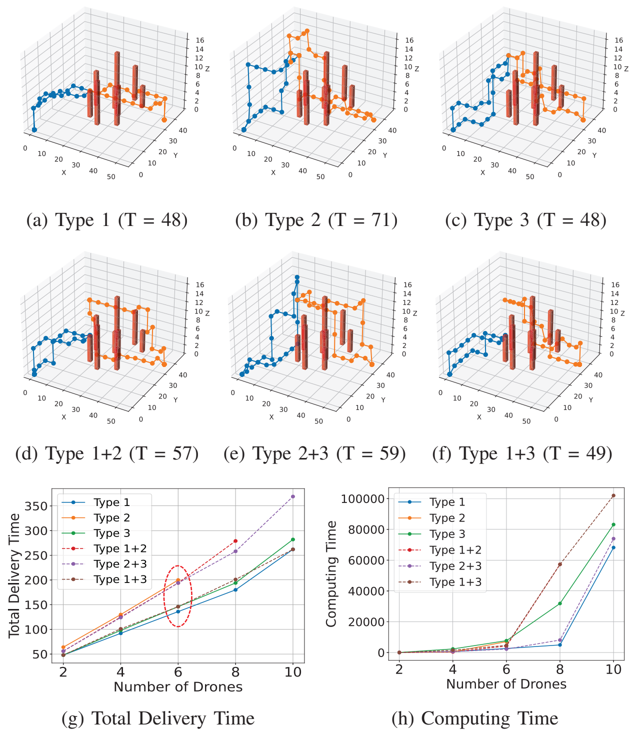

(a) Type 1 (T = 48) (b) Type 2 (T = 71) (c) Type 3 (T = 48)

(d) Type 1+2 (T = 57) (e) Type 2+3 (T = 59) (f) Type 1+3 (T = 49)

(g) Total Delivery Time (h) Computing Time

Fig. 2: Experiment Results

of Type 2 is from when a rope is released for drop-off to when the rope is completely pulled up.

Landing Type 3: A drone hovers over the drop-off location and drop off a parcel itself. Type 3 is similar to Type 2 in that the landing area should be occupied to a similar size. However, Type 3 has generally a shorter landing time because parcels perform free-falling, so they don't have to pull something up.

To this end, we formalize the multi-drone delivery as an optimization problem considering several constraints. The concepts of those constraints are given informally as follows:

- **Drone Dynamics**: Variables that determine drone dynamics, such as speed, acceleration, and flying altitude, are to be bounded by a reasonable minimum and maximum range.
- **Collision Avoidance**: All drones dispatched in the area should avoid collisions and maintain a certain safe distance.
- **Successful Delivery**: All drones shall deliver parcels to their expected drop-off locations; those drones shall also return to the delivery hub for another delivery.
- **Landing Type**: The landing space and time required for each landing type should be satisfied.

Objective: The objective is to minimize the total delivery completion times for multiple drones dispatched in a particular region as follows:

$$\underset{C}{\operatorname{argmin}} \sum_{r \in R} \sum_{u \in U} \sum_{b \in B} T_{r,u,b}, \tag{1}$$

where C is a set of decision variables that represent drone routes, and expressed as $(x,\ y,\ z)^t$ (time-series geographic coordinate); $T_{r,u,b}$ is the delivery completion time for a drone u departs from a delivery hub r to complete deliver a parcel b and to return to the hub r.

Experiment Setting: Gurobi MILP solver is used to solve the optimization problem. We used the WinCopter drone specification to determine several parameters of drone dynamics (*e.g.,* drone speeds); the retrieval time and safety distance were set at 3 seconds and 8 meters away. 9 buildings and 8 delivery hubs are added to model an urban delivery scenario. In Fig. 2, the total delivery completion time (T) and the computing time are obtained by varying the number of drones $\{2, 4, 6, 8, 10\}$, and their landing types $\{$Type 1, Type 2, Type 3, Type 1+2, Type 2+3, Type 1+3$\}$ to verify how they affect optimizing the routes of multiple drones. The ratio of landing types that comprise each composite type (Type 1+2, Type 2+3, Type 1+3) is 1:1. The time limit was 60 hours and timeouts occurred in Type 2 when there were 8 drones, Type 2, and 1+2 when there were 10 drones.

Route Patterns: Fig. 2 (a) — (f) are the samples of the optimal drone routes obtained from our formalized model. Two drones depart from different delivery hubs ([0,0,0], [53, 36, 0]) and deliver the parcels to the same drop-off location ([18,22,6]). Note that all drone routes are different even though their departure and drop-off locations are the same; this shows that the landing type affects the delivery completion time as well; on the other hand, in other literature that simplified such landing types, their routes would have been the same. In particular, Type 2 took the noticeably longest delivery time among all. The reason is that Type 2 requires the drone to hover over the drop-off site, blocking a larger landing area relatively longer than other types, which causes other drones not to enter the area or delay delivery.

Total Delivery Completion Time: Regarding the total delivery completion time, T generally increases as the number of drones increases, as shown in Fig. 2 (g). For the landing type-specific completion time, the delivery completion time with Type 2 only is approximately 38.095% longer than Type 1 only. When different landing types are mixed among multiple drones, T tends to be longer when the mixture involves Type 2. For example, T of Type 2+3 is 28.234% longer than Type 1+3 for 6 drones. This also shows that the landing space and time required by Type 2 noticeably affect the generation of other drone routes.

Problem Complexity: Fig. 2 (h) shows how much computing time is needed as the number of drones increases to demonstrate the complexity of the optimization problem. Computing time increases significantly when the number of drones increases from 6 to 8. This implies that the optimization problem cannot be efficiently solved using a naïve MILP approach for many drones. In the future, we plan to use this MILP-based solution as a baseline and propose a heuristic algorithm that can efficiently compute drone routes to minimize the total delivery completion time. Furthermore, we also intend to perform realistic modeling dealing with route disruption caused by technical issues that can occur in drones.

References

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