A UAV-Assisted Intelligent Delivery System for Smart City

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Abstract

With the cooperation of digital technologies and smart city innovations, an Unmanned Arial Vehicle (UAV) assisted intelligent delivery system is proposed in this paper. The proposed system is an innovative system that helps in reducing the operational delay of the delivery services and provides greater and faster facilities to customers. The whole procedure of the delivery service is managed by the edge-based control stations which serve as the media between the retailers and the UAVs. These stations are distributed over urban areas and are responsible for the assignment of tasks to the UAVs by performing several calculations and communications with retailers and UAVs. By applying the proposed intelligent delivery scheme in smart city applications, it can be expected to reduce delays in delivery services due to the shortage of manual labor and traffic conditions, thus providing greater and faster facilities to the customers.

1. Introduction

Cities are being transformed into smart cities as the current trend of the world in terms of development. Beyond the cooperation of the Internet of Things (IoT) technologies, smart cities enhance the standard of living and wellbeing of the citizens by providing smart services. The goal of every smart city is to bring innovations in urban operations by utilizing information and communications technology (ICT) services and smart solutions [1-3]. Among the various kinds of smart city innovations, the Unmanned Aerial Vehicles (UAVs) contribute to this goal by introducing several services and opportunities. Sustainable developments can benefit from the involvement of UAVs in a wide range of smart city applications and functions.

In this paper, we integrate the aid of UAVs in a package delivery system of the smart city, expecting a reliable and faster service than currently used humans involving third-party delivery services. Those traditional delivery services of using cars and bikes are limited by geographical and terrain features of the location of the customer. In current methods of delivery, if the location of the customer is within a mountainous region or transportation infrastructure at the customer's location is undeveloped, it would be a difficult task to connect the retailer with the consumer. In such situations, traditional delivery services would take a long time to deliver the package to the customer. This can be a crucial factor in medical emergencies in which the delivered package maybe first aid supplies, medicines or blood, and even a few minutes can be the difference between whether someone lives or dies. Even in urban areas, where transportation networks are available, the delivery of a package from a retailer to the customer is affected by traffic conditions resulting in increased delay time. Traditional delivery services depend entirely on human labor which is not available on-demand, whereas autonomous systems can be on standby status round-the-clock. Thus, our objective is to minimize the operational delay in delivery services due to the complex structure of road networks and traffic congestion by proposing the UAV-assisted Intelligent delivery system over the air. Our contributions are summarized as follows:

- We design the system architecture of an edge-based package delivery system to jointly work with UAVs.
- We design a heuristic algorithm to choose the most suitable UAV to perform the package delivery task.
- We propose a novel path planning procedure for a UAV to deliver the package to the customer.

2. System Model and Problem Formulation

We consider an urban area with distributed edge-based control stations that serve as the media between retailers and UAVs. Each control station is capable of data communications between retailers and UAVs and managing the intelligent package delivery service within its respective area. Our system architecture consists of retailers (shops), customers (targets), and a set of parking lots with the charging systems $\mathcal{P} = \{p_1, p_2, \dots, p_{\mathcal{P}}\}$, which are distributed over the area of $10\,km^2$. The locations of each retailer, customer and parking lot can be denoted as $l_r = (x_r, y_r)$, $l_c = (x_c, y_c)$ and $l_p = (x_p, y_p)$, respectively. In each parking lot, there exists a set of fixed-wing UAVs $\mathcal{U} = \{u_1, u_2, \dots, u_{\mathcal{U}}\}$, which are under the control of the same edge-based control station and waiting for the assignment of tasks from it. Without loss of generality, we assume that the UAVs' flight through each traversal path as a straight-and-level flight with a constant speed. Fig.1 shows the system model of the proposed package delivery scheme.

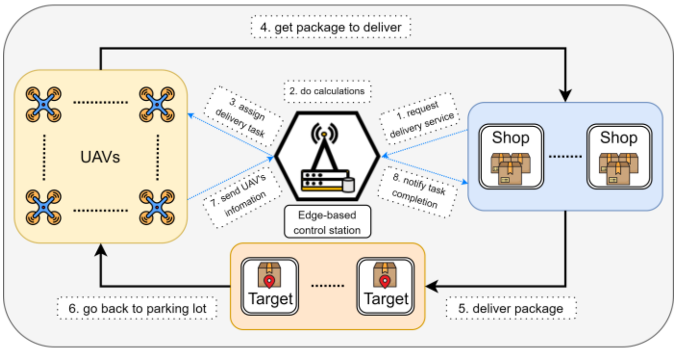

Figure 1. System model

As soon as the edge-based control station gets a request for delivery service from the retailer, it calculates the Euclidean distances between the locations of the retailer and every parking lot in its coverage area by:

$$d(r,p) = \sqrt{(x_r - x_p)^2 + (y_r - y_p)^2}.$$

By comparing the calculated distances, the nearest parking lot to the retailer is found and the control station sorts all the UAVs from that parking lot in descending order of their energy capacities, $E_u^{capacity}$. The minimum energy threshold for each UAV is set as 20% which is much more than the energy required to traverse from the parking lot to the retailer in order to avoid the energy breakdown in the halfway. All the UAVs that do not meet the energy requirement are removed from the list. Then, a UAV with the maximum energy is selected to perform the delivery task if it has not already assigned to a task. Otherwise, the control station will choose the next UAV from the sorted list. In this way, the UAV assignment for the delivery task is performed, and the corresponding procedure is shown in Algorithm 1.

After choosing the most suitable UAV to perform the delivery task, the control station finds the Euclidean distances (i) from the parking lot (UAV's current location) to the retailer calculated by:

$$d_i = \sqrt{(x_u - x_r)^2 + (y_u - y_r)^2 + h^2},$$

and (ii) from the retailer (UAV's next location) to the target customer calculated by:

$$d_{ii} = \sqrt{(x_r - x_c)^2 + (y_r - y_c)^2 + h^2},$$

where h represents a constant flight attitude, which is the minimum requirement for building avoidance. Then, the traversal path for the delivery process is determined by the control station with respect to those calculated distances. Based on the work in [4], the flying energy required by the UAV to perform the delivery task is calculated by:

$$E_u^{flying} = \frac{P_u^{flying}(d_i + d_{ii})}{v\eta_u},$$

where P_u^{flying} is the minimum power required for the forward motion of UAV, v is the average ground speed of UAV and η_u denotes the power efficiency of UAV. As the energy consumption for data transmission is usually much smaller than the flying energy, it is discarded in this paper for simplicity.

Algorithm 1: UAV assignment for delivery process

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Inputs: 𝒫, (x_r, y_r), (x_p, y_p), 𝒰, E_u^capacity
Output: u_n
Let D(r,p) = {}
i ← 1
for p_i in 𝒫 do
    d_i(r,p_i) = sqrt((x_r − x_pi)^2 + (y_r − y_pi)^2)
    Add d_i(r,p_i) to D(r,p)
end for
Select p_i related to min{D(r,p)}
Sort all UAVs from the selected parking lot p_i in the
descending order of energy capacities, E_u^capacity
n ← 1
Let u_n be a UAV with the maximum energy capacity
while true
    if u_n does not have an assigned task then
        Choose u_n for the delivery process
    else
        n = n + 1
end while
```

Fig.2 shows the example scenario of our proposed scheme performing in the designated sample of an urban area. We consider two cases of delivery process, depending on the energy capacity of the assigned UAV. In case 1, where $E_u^{capacity} \geq E_u^{flying}$, the UAV directly navigates to the customer after taking the package from the retailer which is illustrated as the blue solid arrow representing the traversal path of UAV 1 from parking lot 1 in our example scenario. In case 2, where $E_u^{capacity} < E_u^{flying}$, the control station calculates the maximum distance through the determined traversal path that the UAV can traverse by utilizing its energy capacity and selects the parking lot within that coverage, which is nearest to the customer's location, as a checkpoint for transferring the task to another UAV. The task is transferred to and finished by the UAV with the maximum energy capacity from the checkpoint parking lot while the energy-exhausted UAV is recharging. The procedure for case 2 is illustrated in our example scenario as red and violet solid arrows representing the traversal paths of UAV 2 from parking lot 1 and UAV 1 from parking lot 2, respectively. After performing the delivery task, the assigned UAV navigates to the nearest parking lot, goes recharging and the edge-based control station notifies the retailer about the completion of the task.

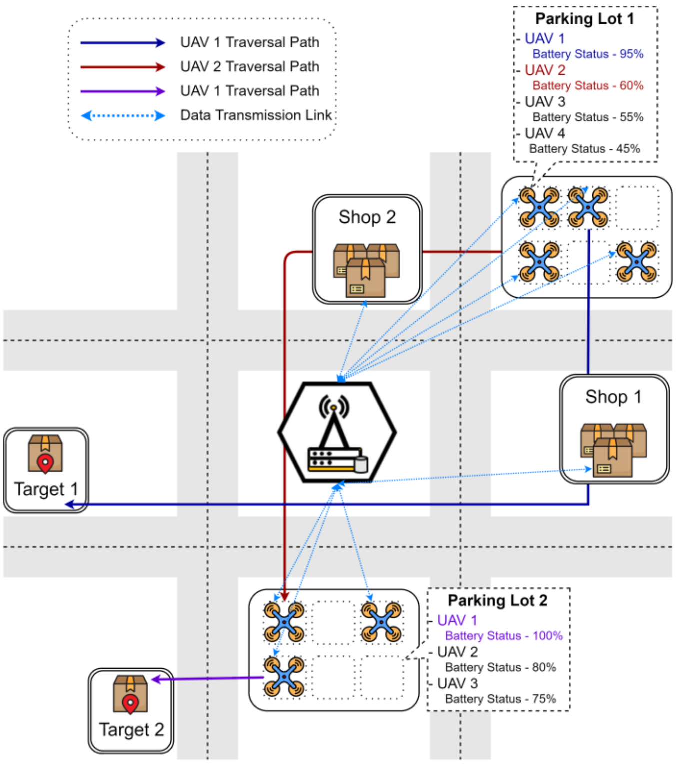

Figure 2. Example scenario

3. Performance Evaluations

In this section, simulation results are discussed to evaluate the performance of the proposed UAV-assisted intelligent delivery system against the currently using third-party delivery service as a benchmarking scheme. We consider a $10\ km^2$ urban area with some retail shops and an edge-based control station as our simulation environment. The locations of parking lots, retailers and customers are distributed uniformly and randomly within that area. In this paper, fixed-wing UAVs are assumed to be capable of flying the distance of $20\ km$ straight by carrying a package of maximum weight $5\ kg$ per each route. The results shown here are averaged over extensive simulations by using a python-based simulator.

Fig.3 shows the average duration required for the UAVs to perform the delivery task with respect to traversal distances. According to the results, our proposed scenario consumed the maximum duration of $250\ minutes$ to deliver the package to the customer $100\ km$ away from the retailer. The current package delivery services usually take from $12\ hrs$ to $48\ hrs$ to operate within the same area due to the artificial operational delay process and traffic congestion. By comparing the results, our proposed system outperforms the current delivery scheme in terms of time consumption and can be expected to give greater and faster facilities to customers.

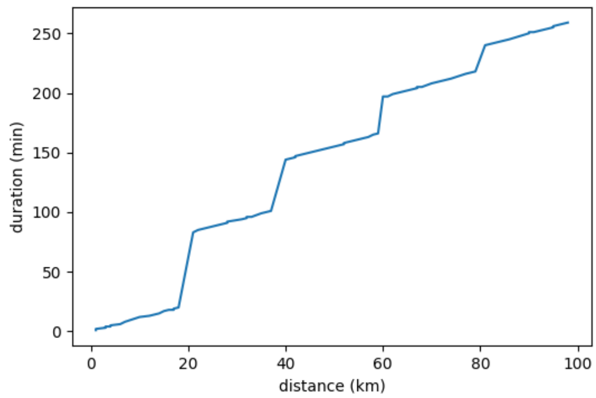

Figure 3. Average duration versus distance traveled for the delivery process

4. Conclusion

In this paper, we proposed an intelligent package delivery system that jointly works with the UAVs and apply it in the smart city domain. We mainly focused on proposing the architecture of a delivery system that efficiently helps in reducing the operational delay by the traditional delivery services. For more general scenarios as optimizing the traversal path and minimizing the energy consumption are considered as our future works.

Acknowledgement

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