A Study on the Intelligent Delivery Management System Using UAV–Edge Computing Technology

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UAV-Edge 컴퓨팅 기술을 활용한 지능형 딜리버리 시스템 연구

(A Study on the Intelligent Delivery Management System Using UAV-Edge Computing Technology)

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요 약 최근 디지털 및 사물인터넷(IoT) 기술의 발전으로 전세계 도시가 스마트시티로 바뀌게 변모하는 추세이다. 또한 IoT 기술과 더불어 무인항공기(UAV) 역시 같이 저렴하고, 더 성능이 우수하며 안정적인 방향으로 기술이 발전되고 있다. 본 논문에서는 IoT와 UAV 기술을 통합 활용한 UAV 지능형 딜리버리 운영 시스템을 제안하고자 한다. 본 논문의 제안사항은 고객에게 더 빠른 서비스를 제공하는 혁신적인 시스템이다. 딜리버리 전반 과정은 소매점과 UAV 간의 전달자로서 역할을 하는 엣지 기반의 제어 스테이션에서 관리한다. 해당 제어 스테이션은 도시 지역에 분산되어 있으며, 소매점들과 UAV 간의 효율적인 연계관리능력을 수행하여 UAV에 최적의 딜리버리 역할을 할당한다. 스마트 시티 애플리케이션에 제안된 지능형 딜리버리 방식을 적용하면 노동력 부족과 교통 상황으로 인한 배송 지연을 줄일 수 있고, 고객에게 더 빠르고 빠른 서비스를 제공할 수 있다.

키워드: 무인항공기, 사물인터넷, 지능형 딜리버리 시스템, 엣지 기반, 스마트시티

Abstract With the recent advancement of the digital and Internet-of-Things (IoT) technologies, cities globally are rapidly transforming into smart cities. In a parallel to the IoT technology, another technology that has substantially improved in recent years is the Unmanned Aerial Vehicle (UAV) technology, resulting in cheaper, more powerful and reliable UAVs. In this paper, we investigate the role of the IoT and propose an intelligent delivery management system in coordination with edge computing and UAV technology. The proposed system is an innovative system that facilitates in reducing the operational delay of the delivery services and provides greater and faster facilities to customers. The whole procedure of the delivery process is managed by the edge-based control stations serving as the media between the retailers and UAVs. These stations are distributed across urban areas and are responsible for assigning tasks to the UAVs by performing crucial calculations and communications between the retailers and UAVs. By applying the proposed intelligent delivery scheme in smart city applications, it can be expected to reduce delays in delivery services because of the shortage of manual labor and traffic conditions, thus providing greater and faster facilities to the customers.

Keywords: unmanned aerial vehicle (UAV), Internet-of-Things (IoT), intelligent delivery system, edge-based, smart city

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1. Introduction

A smart city is an urban area wherein traditional networks and various city services are enabled seamlessly by integrating the digital and telecommunication technologies. As a benefit, a smart city can offer exciting opportunities for its inhabitants and ensure sustainable economic growth in permanent improvement. To the best of our knowledge, 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 [1]. The goal of every smart city is to bring innovations in urban operations by utilizing information and communications technology (ICT) services and smart solutions [2–4].

Among the various kinds of smart city innovations, Unmanned Aerial Vehicles (UAVs) are ready to contribute to this goal by introducing several services and opportunities [5]. Nowadays, research and development on UAV technologies are being carried out in scale and we are starting to see the benefits of utilizing UAVs. Such interest in UAV technologies has already led us to cost-effective UAVs with extensive battery life. Advancement in communication technologies and the implementation of 5G networks have increased the communication reliability of the UAVs and reduced the delay [6]. All these factors show that 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 customer’s location. In current methods of delivery, if the location of a customer is within a mountainous region or the transportation infrastructure at that location is undeveloped, it would be a difficult task to connect the retailer with the customer. 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 package to be delivered may be 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 the traffic conditions resulting in increased delay time.

Moreover, traditional delivery services depend entirely on the 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, traffic congestion and shortage of manual labor 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.

The rest of the paper is organized as follows: Section 2 describes the system model and problem formulation of the proposed intelligent delivery management system. Section 3 explains the use case scenario of our UAV-assisted intelligent delivery management system in the smart city domain. Simulation and performance evaluations are discussed in Section 4. Finally, we provide concluding remarks and future works in Section 5.

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 system within its respective area. Our system architecture consists of retailers (shops) $R = \{r_1, r_2, \ldots, r_R\}$, customers (targets) $C = \{c_1, c_2, \ldots, c_C\}$, and a set of parking lots with the charging systems $P = \{p_1, p_2, \ldots, p_P\}$, which are distributed over the area.
of 10km². 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 \( U = \{ u_1, u_2, \ldots, u_e \} \), 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.

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

\[
d(r, p) = \sqrt{(x_r - x_p)^2 + (y_r - y_p)^2}, \quad \forall p \in P
\]

\[ (1) \]

where \( x_r \) and \( x_p \) represent \( x \)-coordinates, and \( y_r \) and \( y_p \) represent \( y \)-coordinates of the locations of retailer and each parking lot, respectively. By comparing the calculated distances, the nearest parking lot to the retailer is observed. The control station collects the information of UAVs from that parking lot including their current energy percentages, \( E_{u_i}^{current} \), and their current status whether or not they are already assigned to a task. Then, it sorts all the UAVs from that parking lot in descending order of their current energy percentages, \( E_{u_i}^{current} \). 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.

### Algorithm 1: UAV assignment for delivery process

1. **Inputs**: \( P, (x_r, y_r), (x_p, y_p), U, E_{u_i}^{current} \)
2. **Output**: \( u_n \)
3. Let \( D(r, p) = \{ \} \)
4. \( i \leftarrow 1 \)
5. **for** \( p_i \) in \( P \) **do**
6. \( d_i(r, p_i) = \sqrt{(x_r - x_{p_i})^2 + (y_r - y_{p_i})^2} \)
7. **end for**
8. Select \( p_i \) related to \( \min \{ D(r, p) \} \)
9. Sort all UAVs from the selected parking lot \( p_i \) in the descending order of their current energy percentages, \( E_{u_i}^{current} \)
10. \( n \leftarrow 1 \)
11. Let \( u_n \) be a UAV with the maximum energy percentage
12. **while** true **do**
13. **if** \( u_n \) does not have an assigned task **then**
14. Choose \( u_n \) for the delivery process
15. **else**
16. \( n = n + 1 \)
17. **end while**

---

Fig. 1 System model
After choosing the most suitable UAV to perform the delivery task, the control station finds the Euclidean distance \((i)\) from the parking lot (UAV’s current location) to the retailer calculated by:

\[
d_i = \sqrt{(x_i - x_r)^2 + (y_i - y_r)^2 + h^2}
\]  

(2)

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

\[
d_i = \sqrt{(x_i - x_c)^2 + (y_i - y_c)^2 + h^2}
\]  

(3)

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 [7], the flying energy required by the UAV to perform the delivery task is calculated by:

\[
E_{\text{flying}} = \frac{P_{\text{flying}}(d_i + d_{ii})}{\eta_h}
\]

(4)

where \(P_{\text{flying}}\) is the minimum power required for the forward motion of UAV, \(v\) is the average ground speed of UAV and \(\eta_h\) 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. The task-assigned UAV communicates with the control station and navigates the retail shop for taking the package to deliver. After carrying the package, the UAV navigates the target customer and delivers the package. The navigation of UAV throughout the delivery process is under the control of the edge-based control station via the traversal path determined by it.

As soon as the UAV finishes delivering the package to the customer, it sends a notification about the completion of package delivery to the control station. Then, the control station calculates the Euclidean distances between the locations of the customer and every parking lot in its coverage area by:

\[
d(c, p_i) = \sqrt{(x_c - x_{pi})^2 + (y_c - y_{pi})^2}, \forall p_i \in P
\]  

(5)

where \(x_c\) and \(y_c\) represent \(x\)-coordinates, and \(x_{pi}\) and \(y_{pi}\) represent \(y\)-coordinates of the locations of customer and each parking lot, respectively. The control station compares the calculated distances and chooses the nearest parking lot to the customer’s location. Then, it discovers whether there is a free spot for landing and recharging of the task-assigned UAV at the nearest parking lot. If no free spot is available at that parking lot, the control station will consider the second nearest parking lot to the customer’s location. When the whole process of a package delivery system is completed, the UAV sends the task completion status and its remaining energy percentage to the control station. Finally, the control station notifies the retailer about task completion. In this way, the intelligent package delivery system is implemented and the corresponding procedure is provided in Algorithm 2.

### 3. Use Case Scenario in Smart City Domain

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 current energy percentage of the task-assigned UAV. In case 1, where \(E_{\text{current}} \geq E_{\text{flying}}\), the UAV directly navigates to the customer after taking the package from the retailer which is illustrated as a blue solid arrow representing the traversal path of UAV 1 from parking lot 1 in our example scenario. In case 2, where \(E_{\text{current}} < E_{\text{flying}}\), the control station calculates the maximum distance through the determined traversal path that the UAV can traverse by utilizing its current energy 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 and finished by the
UAV with the maximum energy percentage 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 task-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.

4. Performance Evaluations

In this section, simulation results are discussed to evaluate the performance of the proposed UAV-assisted intelligent delivery system. We compare the performance of our proposed system against currently using third-party delivery services as a benchmarking scheme, in which packages are delivered by air, railroad, ship or truck. We consider a 10km² urban area with some retail shops, target customers and an edge-based control station as our simulation environment. Then, we randomly allocate the locations of parking lots, retailers and customers uniformly within that area. In this paper, fixed-wing UAVs are assumed to be capable of flying over the distance of 20km straight by carrying a package of maximum weight 5kg per each route. The statistical 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 100km away from the retailer. The current package delivery services usually take from 12hrs to 48hrs to operate within the same area due to the artificial operational delay process and traffic congestion. By comparing the results, it is clear that 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.

Table 1 shows the delivery durations by different modes of transport for delivering packages, which are average over extensive cases of delivery system. The statistical results listed in this table are transporting time of each method in the unit of time(hrs) per 100km without considering the time consumed.

<table>
<thead>
<tr>
<th>Method</th>
<th>Delivery Duration in hours per 100km</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
</tr>
<tr>
<td>By Air</td>
<td>2.06</td>
</tr>
<tr>
<td>By Railroad</td>
<td>7.50</td>
</tr>
<tr>
<td>By Ship</td>
<td>8.95</td>
</tr>
<tr>
<td>By Truck</td>
<td>5.73</td>
</tr>
<tr>
<td>By UAV (proposed)</td>
<td>4.17</td>
</tr>
</tbody>
</table>
Fig. 4 Duration comparison between different methods of package delivery

by manual operational delay process of the warehouse. Among the various modes of transport, we consider air, railroad, ship and truck as comparative methods for our proposed intelligent delivery system by UAV. According to the table, it is clear that transporting the package by air is the fastest method with the mean of 2.06 and standard deviation of 1.65. But, it is also a costly method and would not be effective in domestic delivery processes. Our intelligent delivery system by UAV is in the second place followed by truck delivery system which is currently, the most practical mode of transport. Delivering the packages by railroad and ship seem not to be compatible and effective in case of minimizing the delivery duration. On the other hand, those two methods are still widely used in transporting large quantities of non-perishable goods in cost-efficient way.

As we can see from Fig. 4, our proposed intelligent delivery system is proven to be the most effective method of transporting the package in comparison with four of the above-mentioned methods of transport. Moreover, the total cost of delivery consumed by our proposed system is much smaller than transporting the package by air or truck. Thus, our proposed system is not only efficient in terms of delivery duration but also it minimizes the cost of delivery more effectively.

5. Conclusion

In this paper, we proposed an intelligent package delivery management system that jointly works with the UAVs under the control of an edge-based control station, 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. The evaluation results show that our proposed system outperforms the currently used delivery schemes in terms of time and cost consumption. For more general scenarios as optimizing the traversal path and minimizing the energy consumption are considered as our future works.

Reference


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