

UAV Path Planning for Minimizing Age of Information in Data Collection

Thanh Phung Truong, 송치현, 이동현, 이충현, 노승환*, and 조성래

중앙대학교, *국립공주대학교

{tptruong, chsong, dhlee, chlee}@uclab.re.kr, rosh@kongju.ac.kr, srcho@cau.ac.kr

Abstract

This paper addresses the challenge of optimizing unmanned aerial vehicle (UAV) path planning to minimize the Age of Information (AoI) in data collection from Internet of Things (IoT) networks. In these networks, IoT devices are grouped and offload their data to the UAV for processing. We transform this problem into a graph-based searching problem, which is then solved using a low-complexity searching algorithm. Our approach ensures efficient data collection, enhancing the freshness of the information gathered from IoT devices and improving the overall performance of IoT systems.

I. Introduction

Unmanned aerial vehicles (UAVs) have garnered significant interest due to their maneuverability and mobility. They are not just technological marvels, but also serve practical purposes. For instance, they can act as wireless relays or mobile base stations, enhancing ground communication and providing reliable network access. This has proven invaluable in applications such as disaster response, surveillance, and monitoring[1].

UAVs can fly close to ground devices and provide low-distance communication links, making them ideal for collecting data from IoT networks. This UAV-aided data collection conserves the energy of IoT devices, extending their lifespan[2]. However, ensuring the freshness of collected data is crucial for time-sensitive applications like environmental monitoring and safety protection, where outdated information can cause severe issues. The age of information (AoI) metric measures data freshness by tracking the time elapsed since the last update. AoI-based data collection guarantees information freshness, attracting increasing attention for its distinct advantages over traditional delay-based and throughput-based metrics.

According to this observation, this work studies path planning for UAVs to collect data from IoT device (IoT) groups, with the primary goal of minimizing the system AoI. To achieve this, we propose a novel path-searching algorithm grounded in a greedy strategy. This algorithm iteratively selects the next best position for the UAV to minimize data AoI from the IoT devices.

II. System Model

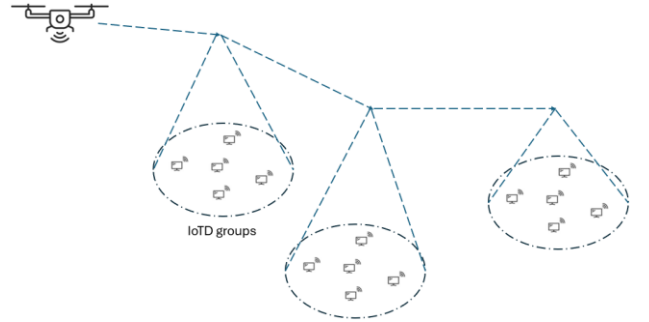


Figure 1. The UAV Path Planning System Model.

The system model considered in Fig. 1 consists of N IoT groups, each has $K_n, n \in \mathcal{N} \triangleq \{1, \dots, N\}$ IoTDs. After each fixed period, the UAV moves through all the groups to collect data. For data transmission, the UAV hovers at the center of each group. Then, the transmission rate from user k of group K_n to the UAV can be calculated as

$$r_{k,n} = \frac{B_n}{K_n} \log_2 \left(1 + \frac{p_{k,n} g_{k,n}}{\sigma^2} \right), \quad (1)$$

where B_n denotes the allocation bandwidth at group n , $p_{k,n}$, $g_{k,n}$, and σ^2 denote the transmit power, the channel gain, and the Gaussian noise power, respectively. In this study, we consider the orthogonal multiple access technique so that there is no interference between multiuser transmission.

Accordingly, the time for user k at group n transmit its data to the UAV is calculated as

$$t_{k,n}^t = \frac{l_{k,n}}{r_{k,n}}, \quad (2)$$

where $l_{k,n}$ denotes the data size to be transmitted of the corresponding user. Then, the total transmission time at group n can be calculated as

$$t_n^t = \max\{t_{k,n}^t, k \in \{1, 2, \dots, K_n\}\}. \quad (3)$$

The UAV is considered to move with a constant velocity v . The time for UAV to move from group the location t to the next location $t + 1$ is calculated as

$$t_{t,t+1}^m = \frac{d_{t,t+1}}{v}, \quad (4)$$

where $d_{t,t+1}$ is the 3D distance between two locations. Then, the AoI at group n can be calculated as

$$AoI_n = AoI_{t-1} + t_n^t + t_{t-1,n}^m, \quad (5)$$

where AoI_{t-1} is the AoI at the previous group with the starting point has an AoI of zero. Consequently, to minimize the AoI of data collection, we formulate the following path planning problem

$$\min_{m \in \mathcal{M}} \sum_{n \in \mathcal{N}} AoI_n, \quad (6)$$

where \mathcal{M} is the set of possible paths that begins from the UAV's starting point, moves through all IoTD groups, and returns to the starting point.

III. Proposed Method

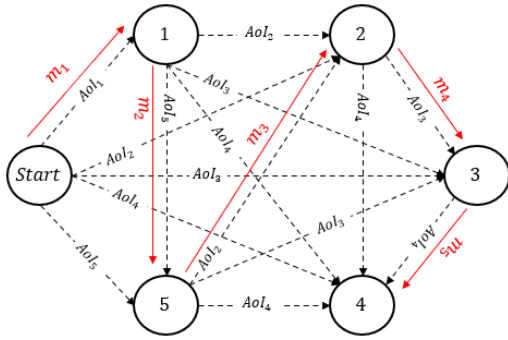


Figure 2. Example of graph-based searching path planning.

We transform the problem into a graph-based search problem. Here, the path planning problem can be expressed by a dynamic directed graph $\mathcal{G} = (\mathcal{V}, \mathcal{E})$, where \mathcal{V} in the edges of graph including all IoTD groups and the starting point, \mathcal{E} is the set of edges in the graph. The edge from node n to node $n + 1$ is calculated as the AoI at group $n + 1$ considering n as the previous node. To find the next node, we estimate the AoIs of all the nodes and choose the node with the smallest AoI.

As an example illustrated in Fig. 2, we consider 5 IoTD groups, which are randomly numbered. First, we estimate the AoI of each group beginning with the starting point. The first group ($t = 1$) can be determined by

$$m_1 = \operatorname{argmax}_n \{AoI_n, n \in \mathcal{N}\}. \quad (6)$$

In this example, we consider $n = 1$ is the first group. The UAV then moves to group 1. Next, we estimate the AoI of the remaining groups. The second group can be determined by

$$m_2 = \operatorname{argmax}_n \{AoI_n, n \in \mathcal{N} \setminus \{1\}\}. \quad (7)$$

As shown in Fig. 2, the second group is chosen as group $n = 5$. The same process continues until there is no group remaining. In this way, we can choose a short path from the starting point to all the nodes with low complexity.

III. Conclusion

In this work, we considered a data collection problem in an IoT network with multiple groups of IoTDs. The UAV plays a role in collecting data from all groups by moving to the center of each group. To minimize the system AoI, we formulated a path planning optimization for UAVs to move to all the groups. The problem was transformed into a graph-based searching problem, and we proposed a low-complexity searching strategy to resolve it.

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