Trajectory Optimization of Cellular-Connected UAV for Information Collection and Transmission

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Abstract—In this paper, we consider a cellular-connected unmanned aerial vehicle (UAV) with an information collection and transmission mission for multiple ground targets. Specifically, the UAV is required to collect a fixed amount of information of each target by hovering at a pre-determined location (via e.g., photography/videography/sensing), and transmit all the collected information to the cellular network during its flight. We aim to jointly optimize the UAV’s trajectory and the information collection order of the ground targets to minimize the mission completion time. The formulated problem is NP-hard due to the need of visiting the information collection locations for all targets; moreover, the UAV’s trajectories over different time durations are coupled in non-convex constraints for ensuring information transmission completion. To handle this difficult problem, we first propose a structured communication protocol between the UAV and the cellular network, which decouples the UAV’s trajectory designs in different time durations. Then, under the proposed protocol, we establish an equivalent graph-based model for the considered problem, and devise a low-complexity algorithm for finding an approximate solution by exploiting the problem structure and leveraging graph theory. Numerical results show that our proposed design achieves efficient information collection and transmission, and outperforms various benchmark schemes.

I. INTRODUCTION

Unmanned aerial vehicles (UAVs) have found numerous interesting applications, due to its highly controllable mobility and swift deployment [1]. To support the various missions of UAVs, it is of paramount importance to realize high-quality UAV-to-ground communications. A promising technology to achieve this goal is cellular-enabled UAV communication [2], or cellular-connected UAV, where UAVs are integrated to the cellular network as new aerial users and served by the ground base stations (GBSs). Unlike existing Wi-Fi based technologies, cellular-enabled UAV communication enables beyond visual line-of-sight (LoS) communication range, low latency, and ubiquitous accessibility by exploiting the high-speed backhaul links among the GBSs in the cellular network.

To maximally harness the benefits of cellular-enabled UAV communication, the UAV’s trajectory needs to be judiciously designed to ensure satisfactory communication performance during its flight. Note that the information communicated between the UAVs and the GBSs can be categorized into two types: low-rate control information for ensuring the safety of UAVs, and high-rate payload information when the UAV needs to acquire information and deliver it to the cellular network.

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develop an equivalent graph-based model of the problem. By exploiting the problem structure, we propose a low-complexity suboptimal solution to the problem. Numerical results demonstrate the superiority of our proposed solution compared to various benchmark schemes based on the traditional TSP method or successive convex approximation (SCA).

II. SYSTEM MODEL

Consider an information collection and transmission mission of a cellular-connected UAV, as illustrated in Fig. 1. The UAV is required to collect information of \( N \geq 1 \) ground targets (e.g., critical infrastructure) by hovering at given locations, and transmit the collected information to a GBS in the cellular network during its flight. The information collection and transmission processes are modeled as follows.

A. Information Collection

Denote \( N = \{1, \ldots, N\} \) as the set of ground targets. To collect the information of each \( i \)-th target, \( i \in N \), the UAV is required to hover at a given information collection point denoted by \( A_i \) for \( T_{C-i} \) seconds (s). The volume of information to be collected for target \( i \) is fixed as \( D_i \) bits. Note that \( A_i \)'s, \( T_{C-i} \)'s, and \( D_i \)'s are pre-determined based on the target properties and information collection methods. For example, \( A_i \)'s can be set as the optimal shooting/sensing positions that achieve the best image/video/sensing quality; \( T_{C-i} \)'s can be set as the required time to complete shooting/sensing of the targets; and \( D_i \)'s can be determined based on the required image/video size and resolution or sensing accuracy.

For ease of exposition, we consider homogeneous targets with a common height of the information collection points \( A_i \)'s denoted by \( H_U \) meters (m), and further assume that the UAV flies at a constant altitude \( H_U \).\(^1\) Let \( u(t) \in \mathbb{R}^{2 \times 1} \) denote the UAV's horizontal location at time instant \( t \), thus the UAV's trajectory projected on the horizontal plane can be expressed as \( \{u(t), t \in [0, T]\} \), where \( T \) denotes the mission completion time of the UAV. We further consider a set of given initial and final points of the UAV denoted by \( U_0 \) and \( U_F \) with horizontal locations \( u_0 \in \mathbb{R}^{2 \times 1} \) and \( u_F \in \mathbb{R}^{2 \times 1} \), respectively, which yields \( u(0) = u_0 \) and \( u(T) = u_F \). The maximum speed of the UAV is denoted as \( V_{\text{max}} \), i.e., \( \|u(t)\| \leq V_{\text{max}}, \forall t \in [0, T] \). Moreover, denote \( a_i \in \mathbb{R}^{2 \times 1} \) as the horizontal location of the information collection point for the \( i \)-th target, \( g \in \mathbb{R}^{2 \times 1} \) as the horizontal location of the GBS, and \( H_G \) as the height of the GBS.

Note that to collect the information of all the \( N \) targets, the UAV needs to visit the \( N \) information collection points \( A_i \)'s one-by-one. Let \( I = [I_1, \ldots, I_N]^T \) denote the information collection order, where \( I_i \in N \) denotes the index of target whose information collection point \( A_i \) is visited in the \( i \)-th order, with \( \{I_i\}_{i=1}^N = N \). We further denote \( t_{i}^O \) and \( t_{i+1}^O \) as the critical time instants when the UAV starts or stops its hovering at \( A_{I_i}, i \in N \) for information collection, respectively, where \( t_{i}^O - t_{i-1}^O = T_{C-i} \). For ease of notation, we further define \( t_{O,0} = 0 \) and \( t_{N+1}^O = T \). Thus, the UAV's trajectory should satisfy
\[
\begin{align*}
  u(t) &= a_i, & t \in [t_{i}^O, t_{i+1}^O), & i \in N, \\
  \end{align*}
\]
\(^1\)The results in this paper can be readily extended to the case with heterogeneous target information collection heights and adjustable UAV altitude.

B. Information Transmission

Between two consecutive information collection stages indexed by \( i \) and \( i+1 \), the UAV flies from information collection point \( A_{I_i} \) to \( A_{I_{i+1}} \) while transmitting the collected information to the GBS during its flight until all the information has been delivered, as illustrated in Fig. 2.\(^2\) It can be observed from Fig. 2 that there are \( N \) information transmission stages in the UAV's mission, where each \( i \)-th stage takes time period \( T_{i}^T = [t_{i}^I, t_{i+1}^I] \). Note that if the information of a target \( I_i \) is not fully transmitted in the \( i \)-th information transmission stage due to limited rate/time, it is stored in the UAV and can be transmitted in the following \((i+1)\)-th to \( N \)-th stages.

We assume that both the UAV and the GBS are equipped with an omni-directional antenna with unit gain. The distance between the UAV and the GBS at time instant \( t \) is expressed as \( d(u(t)) = \sqrt{\|u(t) - g\|^2 + H^2} \), where \( H = H_U - H_G \). For the purpose of drawing essential insights, we assume that the UAV-GBS communication channel is dominated by the LoS link.\(^3\) Thus, the channel power at time instant \( t \) can be expressed as follows under the free-space path loss model:
\[
h^2(u(t)) = \beta_0 |d(u(t))| \beta_0/(\|u(t) - g\|^2 + H^2),
\]
where \( \beta_0 \) denotes the channel power gain at the reference distance \( d_0 = 1 \) m. Let \( B \) denote the bandwidth allocated to UAV-GBS information transmission in Hertz (Hz), \( P \) denote the transmission power at the UAV, and \( \sigma^2 \) denote the average noise power at the GBS receiver. The achievable rate from the UAV to the GBS at time instant \( t \) can be expressed as
\[
\begin{align*}
  R(u(t)) &= \begin{cases}
  \beta_0 B \log_2 \left( 1 + \frac{P \beta_0}{\|u(t) - g\|^2 + H^2}\right), & t \in T_i^T, \ i \in N, \\
  0, & t \notin \bigcup_{i=1}^N T_i^T,
  \end{cases}
\end{align*}
\]
which is non-zero only in the information transmission stages.

Since the information of each \( I_i \)-th target is collected by the UAV at time instant \( t_{O,i} \), it can only be transmitted after \( t_{O,i} \) during the \( i \)-th to the \( (N+1) \)-th information transmission stages denoted by \( \bigcup_{j \in I_i} T_j^T = \bigcup_{j \in I_i} [t_{O,j}, t_{O,j+1}] \). Therefore, it can be easily proved by induction that ensuring successful information transmission for all targets before mission completion is equivalent to guaranteeing that for any \( i \in N \), the total transmitted information volume in the \( i \)-th to the
\(^2\)We assume information collection and information transmission are scheduled in orthogonal time periods, i.e., no information is transmitted when the UAV is hovering at information collection points.

\(^3\)Note that for surveillance applications considered in this paper, the UAV usually flies in rural and remote areas without significant scatters, where the LoS model can characterize the UAV-GBS channel accurately.
N-th information transmission stages is no smaller than the total collected information volume in the i-th to the N-th information collection stages, i.e.,
\[\sum_{j=1}^{N} \int_{t_{i,j}^{O}}^{t_{i,j+1}^{O}} R(u(t))dt \geq \sum_{j=1}^{N} D_{I_{j}}, \forall i \in \mathcal{N}.\] (4)

C. Summary of the UAV’s Mission

In Fig. 2, we summarize the UAV’s overall mission, which is divided into an initial stage \([0, t_{I}^{1}]\), \(N\) information collection stages, and \(N\) information transmission stages. Specifically, in the initial stage, the UAV flies to the firstly visited information collection point \(A_{1}\) without information transmission, since no information has been collected. Then, the UAV sequentially collects information of the next \(N\) targets in \(N\) stages with order \(I\), and performs information transmission during its flight. The overall mission completion time \(T\) can be thus expressed as the sum duration of these stages:
\[T = \sum_{i=1}^{N} T_{i}^{C} + \sum_{j=0}^{N}(t_{i+1}^{I} - t_{i}^{I}).\] (5)

Note that to meet the information collection and transmission constraints in (1) and (4) with minimum mission completion time \(T\), the UAV’s trajectory \(\{u(t), t \in [0, T]\}\) needs to be judiciously designed together with the order \(I\), based on the locations of the ground targets and GBS, as well as the required information volume for each target. For example, if a target with a large information volume is served lastly, the UAV may need to spend a long time in the last information transmission stage, which prolongs the mission completion time. As another example, if a target far away from the initial point is served firstly, the UAV needs to spend a long time flying to that target without any information transmission in the initial stage. Therefore, how to jointly optimize the trajectory and information collection order is a non-trivial problem, which will be investigated in this paper.

III. PROBLEM FORMULATION

In this paper, we aim to optimize the trajectory of the cellular-connected UAV to minimize the completion time of the information collection and transmission mission. By introducing the information collection order \(I\) and critical time instants \(\{t_{i}^{I}, t_{i}^{O}\}_{i=1}^{N}\) as auxiliary optimization variables, the optimization problem is formulated as
\[\min_{I,T,\{t_{i}^{I}, t_{i}^{O}\}_{i=1}^{N}} T \quad \text{s.t.} \quad \sum_{j=1}^{N} \int_{t_{i,j}^{O}}^{t_{i,j+1}^{O}} R(u(t))dt \geq \sum_{j=1}^{N} D_{I_{j}}, \forall i \in \mathcal{N} \] (7)

\[u(t) = a_{I_{i}}, \quad \forall t \in [t_{i}^{I}, t_{i}^{O}], \forall i \in \mathcal{N} \] (8)

\[\|u(t)\| \leq V_{\text{max}}, \quad \forall t \in [0, T] \] (9)

\[{t_{i}^{N+1} = \mathcal{N}, \forall t \in [0, T] \] (10)

\[u(0) = u_{0} \] (11)

\[u(T) = u_{F}. \] (12)

Problem (P1) is a non-convex optimization problem since the constraints in (7) can be shown to be non-convex, which also involve integrals of the rate function that are difficult to be expressed explicitly. Particularly, note that the UAV’s sub-trajectories \(\{u(t), t \in [t_{i}^{I}, t_{i}^{O}]\}_{i=1}^{N}\)’s in different information collection stages are coupled in (7). Moreover, the UAV’s continuous trajectory \(\{u(t), t \in [0, T]\}\) involves an infinite number of optimization variables, which makes (P1) more challenging to solve. On the other hand, (P1) is a combinatorial optimization problem due to the discrete optimization variables in the information collection order \(I\). Note that for the special case with \(D_{I_{i}} = 0, \forall i \in \mathcal{N},\) (P1) is reduced to the classic TSP, which is NP-hard [10]. Therefore, (P1) is also an NP-hard problem, for which the optimal solution is difficult to obtain.

To overcome these challenges, we propose a low-complexity algorithm to find a suboptimal solution of (P1) as follows.

IV. PROPOSED SOLUTION TO (P1)

In this section, we propose a graph theory based approach to find a high-quality suboptimal solution to (P1) with low complexity. Specifically, to resolve the difficulty resulted from the coupling among the sub-trajectories for different information transmission stages in (7), we devise a transmission protocol with a simple structure to decouple these constraints and reformulate the problem. Next, we establish an equivalent graph-based model of the reformulated problem, and propose an efficient algorithm for finding a suboptimal solution.

A. Reformulation of (P1)

First, we reformulate (P1) to decouple the constraints on the sub-trajectories in different information transmission stages. Specifically, we propose a simple information transmission structure to fulfill the constraints in (7), where the \(D_{I_{i}}\)-bit information of each \(I_{i}\)-th target needs to be fully transmitted to the GBS during the \(i\)-th information transmission stage, before the UAV collects information of the next \((I_{i+1}\)-th target. Therefore, the constraints in (7) can be automatically satisfied as long as the transmitted information volume (integrated rate) in each \(i\)-th information transmission stage is no smaller than \(D_{I_{i}}\). Note that the UAV’s trajectory can be equivalently characterized by the sub-trajectories in the initial stage and information transmission stages, \(\{u(t), t \in [t_{i}^{I}, t_{i}^{O}]\}_{i=1}^{N}\); moreover, it follows from (5) that minimizing the mission completion time \(T = t_{i}^{I} + 1\) is equivalent to minimizing the total time in the initial stage and information transmission stages, \(\sum_{i=0}^{N}(t_{i+1}^{I} - t_{i}^{O})\). Therefore, (P1) can be reformulated as follows under the proposed protocol:

\[\min_{\{u(t), t \in [t_{i}^{I}, t_{i}^{O}]\}_{i=1}^{N}} \sum_{i=0}^{N}(t_{i+1}^{I} - t_{i}^{O}) \quad \text{s.t.} \int_{t_{i}^{I}}^{t_{i}^{O}} R(u(t))dt \geq D_{I_{i}}, \forall i \in \mathcal{N} \] (13)

\[\int_{t_{i}^{I}}^{t_{i}^{O}} R(u(t))dt \geq D_{I_{i}}, \forall i \in \mathcal{N} \] (14)

\[\int_{t_{i}^{I}}^{t_{i}^{O}} R(u(t))dt \geq D_{I_{i}}, \forall i \in \mathcal{N} \] (15)

Note that the sub-trajectories in different information transmission stages are no longer coupled in the new information transmission constraints (14), thus making (P2) much more tractable. Moreover, any feasible solution to (P2) is a feasible solution to (P1). In the following, we focus on (P2).
It is worth noting that (P2) is still an NP-hard problem since it can be reduced to a TSP similarly as (P1). Moreover, the discrete optimization variables in \( I \) makes (P2) difficult to be handled by standard optimization methods. Nevertheless, thanks to the decoupled constraints, we are able to establish an equivalent graph-based model for (P2), based on which efficient algorithms in graph theory can be leveraged to find a high-quality approximate solution, as elaborated below.

### B. Equivalent Graph-Based Model for (P2)

In this subsection, we present an equivalent graph-based model for (P2). Note that for any given information collection order \( I \), (P2) aims to minimize the total time duration of the initial stage and \( N \) information transmission stages by optimizing the sub-trajectories in these stages, while ensuring the transmitted information volume in each information transmission stage is no smaller than previously collected information volume for the \( I_i \)-th target, \( D_{I_i} \). Therefore, the optimal solution to (P2) for given \( I \) can be found by optimizing the sub-trajectories of the UAV in the initial stage and \( N \) information transmission stages independently in parallel.

For ease of notation, define \( I_0 = 0, I_{N+1} = N + 1, a_{i0} = u_0, a_{iN+1} = u_F, \) and \( D_{I_0} = 0 \). Let \( T(I_i, I_{i+1}) = t^{I_i}_{i+1} - t^{I_i}_i \) denote the time duration for the initial stage (with \( i = 0 \)) or the \( i \)-th information transmission stage (with \( i \in \mathbb{N} \)), respectively, and \( \{a(t), t \in [0, T(I_i, I_{i+1})]\} \) as the sub-trajectory therein. The problem to optimize each sub-trajectory is formulated as:

\[
\begin{align*}
\min_{\{a(t), t \in [0, T(I_i, I_{i+1})]\}} & \quad T(I_i, I_{i+1}) \\
\text{s.t.} & \quad \int_0^{T(I_i, I_{i+1})} R(a(t))dt \geq D_{I_i} \\
& \quad a(0) = a_i \\
& \quad a(T(I_i, I_{i+1})) = a_{i+1} \\
& \quad \|a(t)\| \leq V_{\max}, \quad \forall t.
\end{align*}
\]

(16)

To address these issues, we propose to find an approximate suboptimal solution to (P2-Sub) by exploiting the optimal solution of (P2) can be found by first obtaining the optimal \( T(0, i), T(i, j), \) and \( T(i, N + 1) \) for all \( i, j \in \mathbb{N}, \) \( i \neq j \) via solving (P2-Sub), and then solving the TSP (P2-O) via exhaustively searching over all the feasible \( I \).

However, such an optimal solution is difficult to be obtained in practice, because the exhaustive search method for (P2-O) incurs complexity \( O(N!) \), while (P2-Sub) is still a non-convex optimization problem due to the non-convex constraint in (17). To address these issues, we propose to find an approximate solution to the TSP (P2-O) with a low-complexity algorithm (e.g., the nearest-neighbour algorithm with complexity \( O(N^3) \)), for which the details can be found in [10] and are omitted here due to limited space. Moreover, we will propose a high-quality suboptimal solution to (P2-Sub) by exploiting the problem structure, as shown in the following subsection.

### C. Proposed Solution to (P2-Sub)

To start with, we derive a useful property of the optimal trajectory for (P2-Sub).

**Proposition 1:** The UAV’s horizontal path corresponding to the optimal solution of (P2-Sub) must lie within a triangle with vertices \( a_{i,j} = a_{i+1,j} \).

**Proof:** Please refer to Appendix A in [11].

Proposition 1 significantly reduces the feasible path range from the infinite space to a finite-sized triangle shown in Fig. 4. Next, we propose three trajectory structures tailored for different information volume requirements within this triangle.
the optimal solution (termed as the time-oriented trajectory) can be easily shown to be the straight-line flight from \( a_i \) to \( a_{i+1} \) with maximum speed \( V_{\text{max}} \), i.e.,

\[
\begin{align*}
\mathbf{u}_T(t) &= a_i + \frac{V_{\text{max}}(a_{i+1} - a_i)}{\|g - a_i\|} t, & t \in [0, T_T(I_i, I_{i+1})],
\end{align*}
\]

where \( T_T(I_i, I_{i+1}) = \frac{\|a_{i+1} - a_i\|}{V_{\text{max}}} \) is the minimum flying time from \( a_i \) to \( a_{i+1} \). The total volume of information transmitted to the GBS with the time-oriented trajectory is

\[
D_T(I_i, I_{i+1}) = \int_{0}^{T_T(I_i, I_{i+1})} R(\mathbf{u}_T(t)) dt,
\]

due to Propositions 1 and 2, we propose a time-rate-balanced trajectory (P2-Sub) illustrated in Fig. 4. Specifically, the UAV first (horizontally) flies from \( a_i \) to a location \( b(I_i, I_{i+1}) \) on the line segment between \( a_i \) and \( g \), and then flies from \( b(I_i, I_{i+1}) \) to \( a_{i+1} \), in straight lines with maximum speed, i.e.,

\[
\begin{align*}
\mathbf{u}_B(t) = \begin{cases} 
\mathbf{a}_i + \frac{V_{\text{max}}(\mathbf{b}(I_i, I_{i+1}) - \mathbf{a}_i)}{\|\mathbf{b}(I_i, I_{i+1}) - \mathbf{a}_i\|} t, & t \in [0, T_B]\n\mathbf{b}(I_i, I_{i+1}) + \frac{V_{\text{max}}(a_{i+1} - \mathbf{b}(I_i, I_{i+1}))}{\|a_{i+1} - \mathbf{b}(I_i, I_{i+1})\|} (t - T_B), & t \in [T_B, T_B(I_i, I_{i+1})],
\end{cases}
\end{align*}
\]

with \( T_B = \frac{\|b(I_i, I_{i+1}) - a_i\|}{V_{\text{max}}}. \)

3) Time/Rate-Balanced Trajectory: Note that the time-oriented trajectory and rate-oriented trajectory are suitable for the cases with low information volume \( D_{T_i} \leq D_T(I_i, I_{i+1}) \) and high information volume \( D_{T_i} \geq D_T(I_i, I_{i+1}), \) respectively. In the following, we consider the case with a moderate information volume \( D_{T_i} \in (D_T(I_i, I_{i+1}), D_R(I_i, I_{i+1}), 0), \) and propose a novel trajectory structure for (P2-Sub) which balances the considerations on the flying time and transmission rate. To start with, we have the following proposition.

**Proposition 2:** If \( D_{T_i} \in (D_T(I_i, I_{i+1}), D_R(I_i, I_{i+1}), 0), \)

\[
\begin{align*}
\frac{D_{T_i} - D_R(I_i, I_{i+1})}{R(g)} = \frac{D_{T_i} - D_R(I_i, I_{i+1})}{B \log_2(1 + \frac{\rho_0 \gamma^2}{4 \pi^2})},
\end{align*}
\]

where \( \epsilon \) characterizes the precision requirement of the bi-section search in Section IV-C3.
the SCA-based methods is

\[
H = H_U - H_G = 100 \text{ m}
\]

We consider \( N = 4 \) targets, whose horizontal locations are \( a_1 = [0, 0]^T \), \( a_2 = [100, 100]^T \),

\[
a_3 = [-30, -800]^T, \quad a_4 = [70, -900]^T, \quad \text{respectively, as illustrated in Fig. 6.}
\]

The horizontal locations of the GBS, \( U_0 \), and \( U_F \) are \( g = [20, -500]^T \), \( u_0 = [-100, -400]^T \), and \( u_F = [150, -400]^T, \quad \text{respectively.}
\]

Denote \( \{D_i = \alpha D_t\} \) as the required information volume for the 4 targets, where \( \alpha \) is a scaling factor; \( D_1 = 3 \times 10^8 \), \( D_2 = 7 \times 10^8 \), \( D_3 = 2 \times 10^8 \), and \( D_4 = 6 \times 10^8 \) are a set of reference volume. For comparison, we consider the following benchmark schemes:

- **Distance-based TSP:** In this scheme, we design the information collection order \( I \) to minimize the total flying distance from \( U_0 \) to \( U_F \) while visiting all information collection points via the TSP algorithm [10]. Based on the obtained \( I \), the trajectory is designed based on our proposed path structure according to (33), (21), and (22).

- **SCA with path/time discretization:** Note that (P2-Sub) can also be handled via the SCA method, by first approximating the continuous trajectory with discrete line segments, and then optimizing the end points of them via successively solving a convex approximation of (P2-Sub). In these schemes, we adopt the SCA method with path or time discretization [1] to find a suboptimal solution of (P2-Sub), based on which \( I \) is designed via the TSP algorithm over graph \( G \).

In Fig. 5, we show the mission completion time \( T \) for different schemes versus \( \alpha \), where we set \( T_i^C = 0, \forall i \) for simplicity. It is observed that the proposed solution requires the minimum mission completion time among all schemes for all values of \( \alpha \), since our judicious design of the information collection order and UAV’s sub-trajectories by exploiting the unique problem structures is able to well balance between the required time and transmission rate. In Fig. 6, we show the trajectories of different schemes for \( \alpha = 1 \). It is observed that the information collection order designed based on graph \( G \) in (24)-(26) for both our proposed solution and the SCA-based methods is \( I = [1, 2, 3, 4]^T \), while that for distance-based TSP is \( I = [3, 4, 1, 2]^T \). Note that the latter is unfavorable since the information of target 2 with largest required volume is lastly collected, thus requiring long time duration for the last information transmission stage. On the other hand, the SCA-based trajectories generally have curved paths of longer lengths compared to those in the proposed solution and distance-based TSP. Moreover, it can be observed from Fig. 5 that the performance gap between the SCA-based methods and our proposed solution increases as the required information volume increases, due to the inaccuracies in the problem approximation and trajectory discretization. This further demonstrates the superiority of our proposed trajectory structure tailored for the considered problem.

### VI. Conclusion

In this paper, we studied a cellular-connected UAV which needs to hover at multiple fixed locations for information collection, and transmit the collected information to the GBS during its flight. We formulated the joint optimization problem of the UAV’s trajectory and the information collection order to minimize the mission completion time, which is an NP-hard problem. By devising structured communication protocols, we reformulated the problem into a more tractable form, and established a graph theory based method for finding a high-quality suboptimal solution. Numerical results showed that our proposed solution outperforms various benchmark schemes.

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