1. INTRODUCTION
Unmanned aerial vehicles (UAVs) have received growing interests in various applications such as cargo delivery, filming, rescue, and search, as well as wireless platforms [1] [2]. To provide seamless communication for UAVs to maintain their safe cooperation, cellular-connected UAV communication has recently been emerging. UAVs can act as low-cost and mobile users in cellular networks [3] [4]. Nevertheless, with their size, weight, and power (SWAP) limitations, UAVs usually have limited computation resources to handle computation-intensive and yet latency-critical tasks.

This paper proposes a new approach by jointly exploiting the techniques of mobile edge computing (MEC) and cellular-connected UAV communication. UAVs with cellular connection can offload their intensive computation tasks to ground base stations (GBSs) integrated with edge servers for remote execution. As GBSs are nowadays deployed almost everywhere, UAVs can connect to them with seamless communication and ubiquitous computation services. This helps increase their operation range and enlarge their application horizon.

With high-mobility UAV users in MEC systems, some new opportunities and challenges are shown up.

- A UAV user in the sky usually possesses stronger and more reliable line-of-sight (LoS) links with many GBSs at the same time. This thus enables each UAV to simultaneously connect with multiple GBSs to exploit their distributed computing resources.

2. SYSTEM MODEL AND PROBLEM FORMULATION
This paper investigates a new MEC application scenario where a cellular-connected UAV offloads its computation tasks to multiple GBSs along its trajectory. Specifically, we assume that the UAV trajectory has been planned a priori and is fixed. The joint UAV trajectory and computation offloading optimization problem is formulated as

\[ \min_{(w(t), U(t))} c(t) + \left( \frac{1}{2} \beta \sum_{i=1}^{N} (u_i - \bar{u})^2 \right) \]

subject to

\[ \|u(t) - w(t)\|_2 \leq \bar{u} \]

\[ \text{subject to} \quad (1) \text{ and (2)} \,, \quad (3) \,, \quad (5) \,, \quad (6) \].

3. PROPOSED SOLUTION TO (P1)
We sub-optimally solve (P1) equivalently by first optimizing over \(w(t)\) and \(R_i(t)\) under any given \(N\), and then using a bisection search to find the optimal \(N\). Let \(N^*\) denote the optimal solution of \(N\) to (P1).

3.1 Feasibility Checking Problem
Under any given \(N\), (P1) becomes the following feasibility checking problem:

\[ \text{subject to} \quad (1) \text{ and (2)} \,, \quad (3) \,, \quad (4) \,, \quad (5) \,. \]

If \(P2\) is feasible under \(N\), then it follows that \(N^* \geq N\); otherwise, we have \(N^* > N\).

3.2 Solving Problem (P2) Given \(N\)
Note that solving (P2) is equivalent to solving the following problem (P3) to maximize the number of computation-task offlodees \(L\). We have

\[ \text{maximize} \quad L \]

subject to

\[ \sum_{i=1}^{N} \sum_{t=1}^{T} R_i(t) \leq L \]

(1)

\[ \text{subject to} \quad (2) \,, \quad (3) \,, \quad (4) \,, \quad (5) \,. \]

If \(L \geq 2\), then (P2) is feasible; otherwise, (P2) is infeasible.

3.3 Suboptimal Solution to (P3): We jointly optimize the time allocation \(R_i(t)\) and the UAV trajectory \(w(t)\) in an alternating manner to solve (P3).

- Time Allocation for (P3) Under Given UAV Trajectory:
  Under given \([w(t) \mid (1)\], (P3) is reduced to

\[ \max_{L \leq T \sum_{i=1}^{N} R_i(t)} \sum_{i=1}^{N} \sum_{t=1}^{T} R_i(t) \leq L \]

(3)

- UAV Trajectory Optimization for (P3) Under Given Time Allocation:
  Under given \([R_i(t) \mid (3)]\), (P3) is reduced to

\[ \text{maximize} \quad \sum_{i=1}^{N} \sum_{t=1}^{T} R_i(t) \]

subject to

\[ \|w(t) - R_i(t)\|_2 \leq \bar{u} \]

(4)

Next, consider constraint (7). By taking the first-order Taylor expansion of \(R_i(t)\) with respect to \(w(t)\), we can write a lower bound of \(R_i(t)\):

\[ R_i(t) \geq \min_{w(t)} \left( \|w(t)\|_2 \leq \bar{u} \right) \]

(9)

Finally, this is approximated as (P3.3). It can be solved optimally via CVX.

\[ \text{maximize} \quad \sum_{i=1}^{N} \sum_{t=1}^{T} R_i(t) \]

subject to

\[ \|w(t) - R_i(t)\|_2 \leq \bar{u} \]

(6)

\[ \|w(t)\|_2 \leq \bar{u} \]

(10)

4. NUMERICAL RESULTS
There are \(K = 5\) GBSs that are distributed within a geographic area of size \(1 \times 1 \text{km}^2\). At each GBS, we set \(\beta = 2\), \(\gamma = 1\), \(\zeta = 3\), (TDMA) cycles/GBS. Let \(P = 1\) MHz, \(\bar{u} = 50 \text{ Mbits} / \text{s}\), and \(P = 0.01 \text{ W}\). The channel power gain at the reference distance of 1 m is \(\delta = -30 \text{ dB}\) and the noise power is \(\sigma^2 = -60 \text{ dBm}\). We validate the performance of our proposed design comparing with the following benchmark schemes.

- Straight flight: the UAV flies straightforwardly with the initial/local final location.
- Successive hover-and-fly: the UAV flies to successfully reach the top of the X GBSs at the maximum speed, and hovers above each of them for computation offloading.

5. CONCLUSION
This paper investigates a new MEC application scenario where a cellular-connected UAV offloads its computation tasks to multiple GBSs along its trajectory.

- The UAV trajectory is jointly designed with the computation offloading scheduling, to minimize the mission completion time subject to the UAV’s maximum speed and initial/local final constraints, as well as the GBS’s individual computation capacity constraints.
- By exploiting alternating optimization and SCA techniques, an efficient algorithm is proposed to solve the formulated problem suboptimally.
- Numerical results show a prominent performance gain of our design over the benchmark schemes.

REFERENCES