A Hybrid Approach to Traffic Offloading Optimization in Multi-UAV Cellular Networks

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Introduction

Background

- UAV cellular network base station → Extra bandwidth, emergency traffic, flexible deployment
- Traffic Offloading Techniques → Relieving Congestion in UAV Cellular Networks.
- Lack of research on multi-drone traffic offloading to cellular networks

Preset conditions

Nlos communication channel → Corresponds with reality
Grouping of users → Ensure full utilization of drone transmission resources
Ensure the distance between drones → Avoid mutual interference
Reducing drone movement distance → Reduce power loss to improve service time

Contribution

- Multiple UAVs collaborate to provide transmission services
- The total distance traveled by UAVs is a partial optimization objective to reduce power loss
- Modeling the traffic offload proportional distribution problem as an MDP
- Use mean-shift algorithm, minimum cost maximum flow algorithm and reinforcement learning approach to solve the problem together

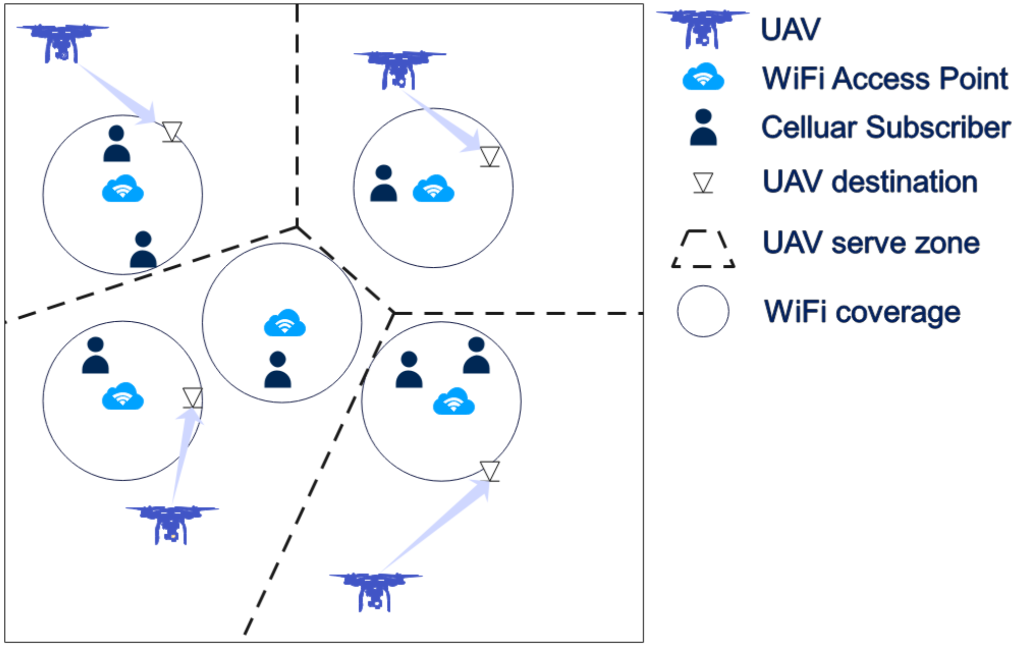
Related Work

- **related work**
  - Iman Valiulahi [1] and others use meanshift to maximize throughput for multi-UAV deployment
  - Yong Zeng [2] used SCA for UAV communication energy minimization
  - Shanza Shakoor [3] used k-means to maximize user access rate for UAV networks
  - Xuanheng Li [6] Joint optimization of UAV trajectory, data acquisition, and transmission power based on DQN to maximize UAV transmission energy
  - Muntadher A. Ali [7] et al. Optimized traffic allocation ratio, drone position and band allocation ratio by block coordinate optimization descent method to minimize average delay
- ***Our research***

Related Works	Our Research	Advantage
Throughput Maximization, Energy Minimization, Access Rate Maximization	Latency Minimization	Newer research area
Average latency minimization	Maximum latency minimization	Fairness
Single drone + los channel	Multi-drone + nlos channel	Realistic

System Model

- All users are on some wifi LAN
- Multiple drones, each serving a group of users with additional bandwidth
- Drone height is determined
- m/m/1 queuing model



System Model

- **Relevant definitions**

N_{UAV} :Unmanned Aerial Vehicles (UAVs) number.

N_{CS} :Cellular Subscriber(CS) number

q_i:CS_i postion.

w_i:UAV_i postion.

$D_{\min}$: Minimum distance between UAVs ($|w_i - w_j| \geq D_{\{\min\}}$ ($\forall i, \forall j$))

$a_{i,j} = 1$: Indicate that CS_i is served by UAV_j

λ_i: the traffic demand of CS_i

μ_i: the ratio of CS_i traffic offloading

$\lambda_i^{AP} = \mu_i \lambda_i$: CS_i traffic demand transmittedvia WiFi Access Point(AP)

$\lambda_i^{UAV} = (1 - \mu_i)\lambda_i$: CS_i traffic demand transmitted via UAV

Θ_j : The total throughput of AP_j

$R_i^{AP} = \frac{\Theta_j}{N_j^{AP}}$:the transmission rate of CS_i within its corresponding AP_j

$R_i^{UAV} = \frac{\lambda_i^{UAV} BS_i}{\sum_{i=1}^{N_{CS}} \lambda_i^{UAV}}$:the transmission rate of CS_i at the UAV

B:bandwidth of the UAV .

P: transmit power.

N_0 :Gaussian noise power.

$\delta_i^{UAV} = \frac{1}{(R_i^{UAV} - \lambda_i^{UAV})^+}$:the delays of CS_i on UAV

$\delta_i^{AP} = \frac{1 + 0.5 R_j^{AP} \lambda_i^{AP} v_i}{(R_j^{AP} - \lambda_i^{AP})^+}$:the delays of CS_i on AP.

$\sum_i^{UAV} d_i$:the distance traveled by all UAVs

Problem Formulation

$$\min_{w,\mu_i,a} \quad \delta^{max} + k \sum_{i}^{UAV} d_i \qquad (1)$$

$$\text{s.t.} \quad \lambda_i^{UAV} \leq R_i^{UAV}, \forall i \in N_{CS} \qquad (a)$$

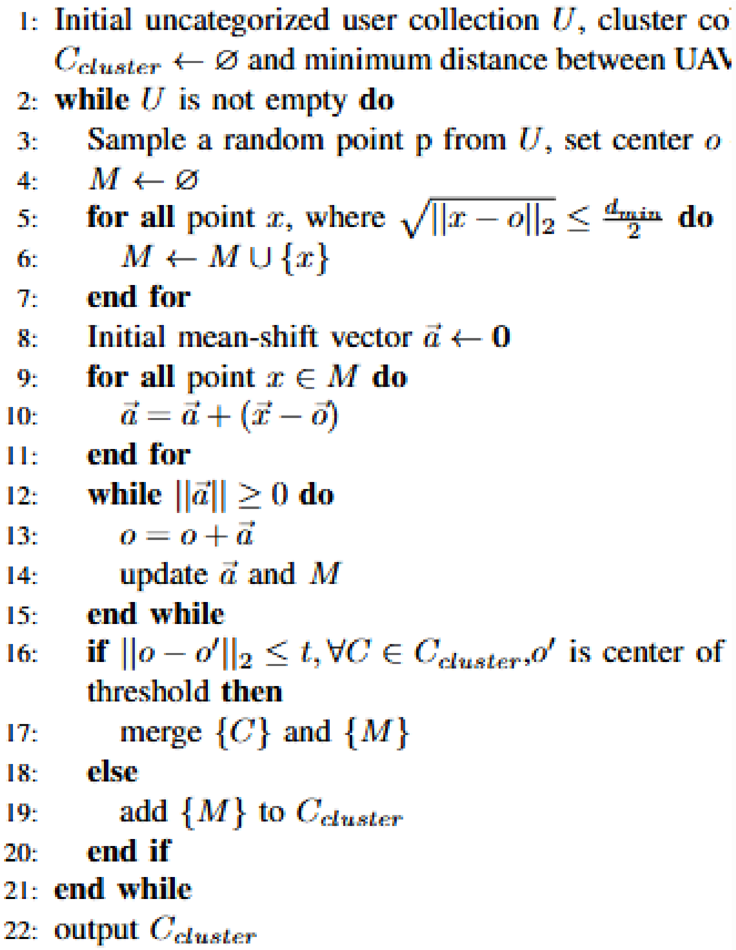
$$\lambda_i^{AP} \leq R^{AP}, \forall i \in N_c \qquad (b)$$

$$|w_i - w_j| \geq D_{min}(\forall i, \forall j \in N_{UAV}) \qquad (c)$$

$$\sum_{j=1}^{N_{UAV}} a_{i,j} = 1, a_{i,j} \in \{0,1\}(\forall i \in N_{CS}) \qquad (d)$$

- ***coefficient k:*** *importance of the distances moved by the UAVs.*
- ***constrain a:*** *the transmission rate of the CS on the UAV should be greater than the traffic demand transmitted by the UAV*
- ***constrain b:*** *the transmission rate of the CS on the AP should be greater than the traffic demand transmitted by the AP*
- ***constrain c:*** *the UAVs should be kept at a minimum distance from each other*
- ***constrain d:*** *the user allocation scheme should satisfy that each user is served by one UAV.*

Mean-shift: Solves the user grouping problem

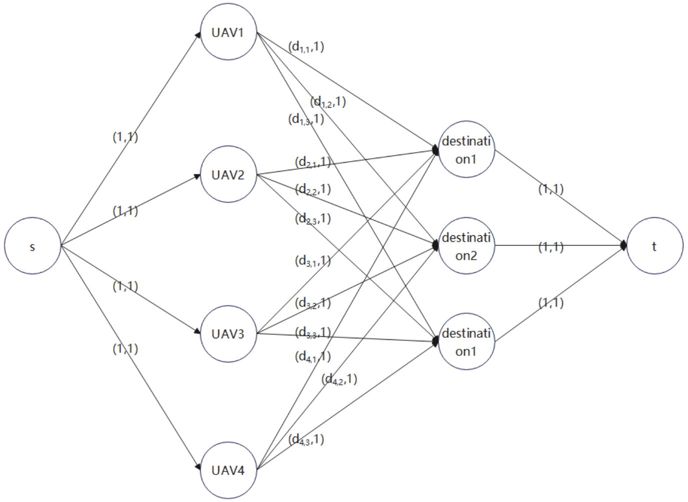


```
Initial uncategorized user collection $U$, cluster co
$C_{cluster} \leftarrow \varnothing$ and minimum distance between UAV
while $U$ is not empty do
    Sample a random point p from $U$, set center $o$
    $M \leftarrow \varnothing$
    for all point $x$, where $\sqrt{||x-o||_2} \leq \frac{d_{min}}{2}$ do
        $M \leftarrow M \cup \{x\}$
    end for
    Initial mean-shift vector $\vec{a} \leftarrow \mathbf{0}$
    for all point $x \in M$ do
        $\vec{a} = \vec{a} + (\vec{x} - \vec{o})$
    end for
    while $||\vec{a}|| \geq 0$ do
        $o = o + \vec{a}$
        update $\vec{a}$ and $M$
    end while
    if $||o - o'||_2 \leq t, \forall C \in C_{cluster}, o'$ is center of
    threshold then
        merge $\{C\}$ and $\{M\}$
    else
        add $\{M\}$ to $C_{cluster}$
    end if
end while
output $C_{cluster}$
```

- **Advantages of mean-shift over k-means:** ensure that each group of users is centered a certain distance away from each other
  - The meanshift algorithm treats points with distances less than a certain value as being of the same class.
  - The meanshift searches for the largest set of points that have a distance less than a constant value from each other.
  - The points in the current point set are classified into one category, and the points are removed from the unclassified points.
  - The process of classification is repeated until all points are categorized into a particular class.
- **After mean-shift end, we assign drones to these m classes**

UAV Navigation Minimization

Statutes for Minimum Cost Flow Problems



N_{UAV} **drones** :the nodes in the first column

m **cluster centers (destination):** the nodes in the second column.

edge between UAV and destination :

- capacity = 1.
- cost = the distance between UAV and destination.

other egde:

- capacity = 1.
- cost = 1

The original problem	equivalence problem
Assigning N_{UAV} drones to m cluster centers and minimizing the total distance	Finding in the constructed graph a capacity of m minimum cost flow.

Bellman-ford algorithm can solve the equivalence problem.

DRL method

--solve the problem of proportionate distribution of user traffic allocation

- **Why DRL?**

non-line-of-sight channel(nlos)

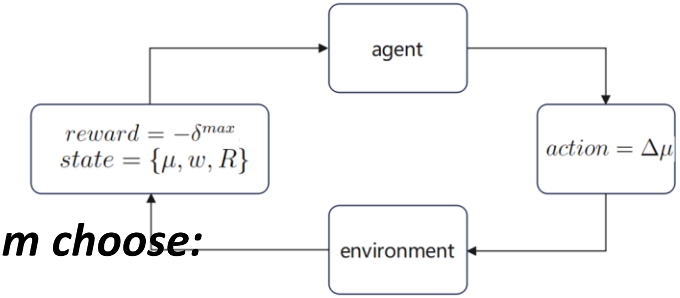
→ The communication rate is no longer inversely proportional to distance squared.

→ Traditional convex optimization methods is invalid

- ***MDP model***

$$reward = -\delta^{max} - \alpha\left(\sum_i^{N_{cs}} I(R_i^{UAV} - \lambda_i^{UAV}) + \sum_j^{N} I(R_j^{AP} - \lambda_j^{AP})\right)$$

$$action = \Delta\mu$$


agent

$reward = -\delta^{max}$
$state = \{\mu, w, R\}$

$action = \Delta\mu$

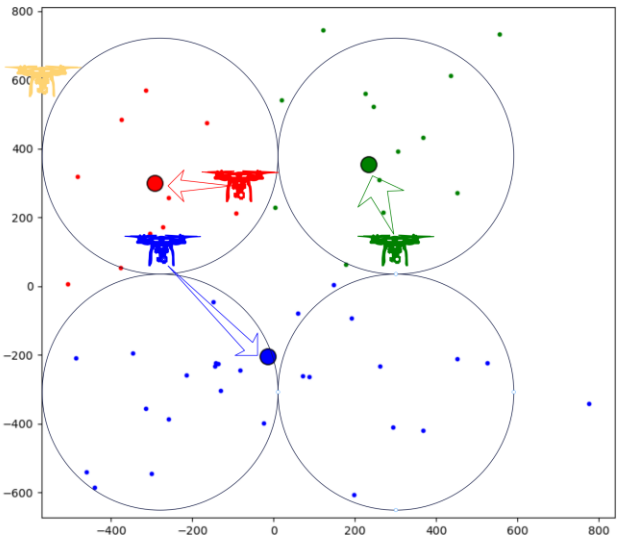
environment

- ***DRL argorithm choose:***

DRL argorithm	Specificities
DQN	Discrete action space, not applicable
NPG,TRPO	KL dispersion is complex to compute and slow to converge
PPO	The clip method restricts the update step size and has fast and stable convergence

Experiment result

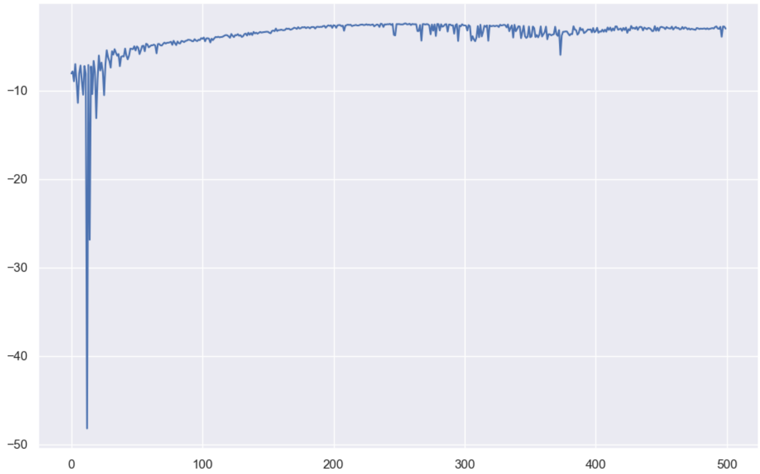
- **mean-shift result:**



- ***bellman-ford result:***

initial position	target position
(-600,600)	Stays stationary
(-100,300)	(-293.72,299.73)
(-300,100)	(-14.75,-203.56)
(300,100)	(232.65,353.24)

- ***DRL result:***



Summary

- Traffic offloading with multiple drones as base stations
- Reduce total drone distance to reduce drone power consumption
- Optimize maximum delay to enhance fairness
- Adopting a more realistic nLos channel model
- Slove using the meanshift algorithm, the statute as a minimum cost maximum flow problem, and the DRL approach

Thanks for Listening!