MADRL Based Offloading Policy and UAV Trajectory Design in F-MEC Systems

1st Given Name Surname

***Abstract*—**
***Index Terms*—**

I. INTRODUCTION

II. RELATED WORK

III. SYSTEM MODEL AND PROBLEM FORMULATION

A. System Description

As shown in Fig.1, we consider an F-MEC system with multi-UAVs collaboratively providing service for a set of UEs. The UAVs are divided into two groups, namely energy transmitting UAVs (ET-UAVs) and data processing UAVs (DP-UAVs). Specifically, the ET-UAVs are responsible for providing energy to the UEs for data collection, while the DP-UAVs are dedicated to collecting and processing data, and the sets of them are denoted by $\mathcal{M}^l = \{1, 2, ..., M^l\}$ respectively, where $l \in \{\text{ET,SP}\}$. We assume that there are N randomly distributed UEs in the system, which are denoted by $\mathcal{N} = \{1, 2, ..., N\}$. Besides, we consider a single base station (BS) with computation capacity and a satellite relay in this model, which are both connected to a data center (DC).

B. Movement model

Similar to the works in [] [], the service time is discretized into K time slots with the same duration Δ, which is denoted as $\mathcal{K} = \{1, 2, ..., K\}$. Noted that Δ is short enough compared to the service time, which means that the movement of the UAVs and the UEs is negligible in each time slot. Suppose that the location of the i-th UE at the k-th time slot is denoted as $\mathbf{w}_i(k) = [x_i(k), y_i(k)]^T, i \in \mathcal{N}$, and it can be obtained by the UAVs via the sensors equipped onboard. We assume that the l-UAVs fly at a fixed height H^l, and the horizonal location of the j-th l-UAV is denoted by $\mathbf{q}_j^l(k) = [x_j^l(k), y_j^l(k)]^T$. Given the maximum velocity of the UAVs V_{MAX}, the maximum speed constraint can be expressed as:

$$||\mathbf{q}_j^l(k) - \mathbf{q}_j^l(k-1)||_2 \leq V_{\text{MAX}}\Delta, \quad \forall j \in \mathcal{M}^l, k \in \mathcal{K}. \tag{1}$$

To avoid collision among the UAVs, the location of the UAVs should satisfy:

$$||\mathbf{q}_j^l(k) - \mathbf{q}_{j'}^l(k)||_2 \geq D_{\min}, \quad \forall j \neq j' \in \mathcal{M}^l, k \in \mathcal{K}. \tag{2}$$

The service area is defined as a rectangular field, so we have:

$$0 \leq x_j^l(k) \leq X, \quad \forall j \in \mathcal{M}^l, k \in \mathcal{K}, \tag{3}$$
$$0 \leq y_j^l(k) \leq Y, \quad \forall j \in \mathcal{M}^l, k \in \mathcal{K}. \tag{4}$$

According to [], the flying power of the rotary-wing UAV can be modeled as a function of velocity:

$$\begin{aligned} P^{\text{F}}(v) =& P_0\left(1+\frac{3v^2}{U_{tip}^2}\right) + P_i\left(\sqrt{1+\frac{v^4}{4v_0^4}} - \frac{v^2}{2v_0^2}\right)^{\frac{1}{2}} \\ &+ \frac{1}{2}d_0\rho s G v^3. \end{aligned} \tag{5}$$

The three terms of (6) are blade profile power, induced power and parasite power respectively, among which P_0 and P_i are constants, U_{tip}, v_0, d_0, s and G are parameters related to the UAV properties, and ρ is the parameter related to the flying environment. Therefore, with the UAV's velocity $v^l(k)$, the energy consumption in time slot k is given by:

$$E_j^{l,\text{F}}(k) = P^{\text{F}}\left(v^l(k)\right) \cdot \Delta. \tag{6}$$

C. Communication model

1) Communication model between the UEs and the UAVs: Considering the air-to-ground path loss probability in the disaster affected areas, the probability of line-of-sight (LoS) channel can be modeled as a function of the angle θ between the UAV and the UE [1]:

$$\Pr(\theta) = \frac{1}{1 + C\exp\left(-D(\theta - C)\right)}, \tag{7}$$

where C and D are constants related to the built-up land ratio, building density and building height, and $\theta_{i,j}^l$ is the angle between the i-th UE and the j-th l-UAV at the k-th time slot, which can be calculated with the following formula:

$$\theta_{i,j}^l(k) = \frac{180}{\pi}\arcsin\left(\frac{H}{||\mathbf{q}_j^l(k) - \mathbf{w}_i||_2}\right). \tag{8}$$

Hence, the average channel gain is represented as:

$$\begin{aligned} h_{i,j}^l(k) =& \Pr(\theta_{i,j}^l(k))\chi\beta_0[d_{i,j}^l(k)]^{-\alpha} + \\ & \left(1 - \Pr(\theta_{i,j}^l(k))\right)\beta_0[d_{i,j}^l(k)]^{-\alpha} \\ =& \hat{\Pr}(\theta_{i,j}^l(k))\beta_0[d_{i,j}^l(k)]^{-\alpha}, \end{aligned} \tag{9}$$

where β_0 and χ are attenuation coefficients, α is path loss exponent. $\hat{\Pr}(\theta) = \Pr(\theta)\chi + (1 - \Pr(\theta))$ denotes the e-quivalent attenuation coefficient considering the LoS channel, and $d_{i,j}^l(k)$ represent the distance between the j-th l-UAV and the i-th UE, which is defined by $d_{i,j}^l(k) = \sqrt{||\mathbf{q}_j^l(k) - \mathbf{w}_i||_2^2 + H^2}$.

For the energy transmission process between the ET-UAVs and the UEs, we assume that the energy harvesters at the UEs do not operate in the saturation region, and the received power from the ET-UAVs is not high, so the linear energy harvesting model is adopted [2]. Hence, the total harvested energy from all ET-UAVs at time slot k can be expressed as:

$$E_{i,j}^{\mathrm{UE},h}(k) = \sum_{j=1}^{M^{\mathrm{ET}}} \eta_i h_{i,j}^{\mathrm{ET}}(k) E_j^{\mathrm{ET},tr}, \tag{10}$$

where $0 < \eta_i < 1$ is the energy conversion efficiency of device i, and $E_j^{\mathrm{ET},tr}$ represents the transmit energy of the j-th ET-UAV at each time slot.

For the data transmission between the DP-UAVs and the UEs, we firstly define the set of UEs within the coverage area of DP-UAV j as $\mathcal{N}_j^{\mathrm{DP}} = \{i \in \mathcal{N} : ||\mathbf{q}_j^l - \mathbf{w}_i||_2 \leq D^{\mathrm{DP},c}\}$, where $D^{\mathrm{DP},c}$ is the horizontal coverage distance of the DP-UAV. Assuming that the DP-UAVs can connect to all the UEs in $\mathcal{N}_j^{\mathrm{DP}}$ at each time slot, and the orthogonal frequency division multiplexing (OFDM) system is applied in this model, which means that there is no interference between the uplink transmissions of the UEs. Hence, the transmission rate is expressed as:

$$r_{i,j}(k) = B_a \log_2 \left(1 + \frac{h_{i,j}(k) P_i^{\mathrm{UE},tr}}{\sigma^2}\right) \tag{11}$$

where B_a denotes the bandwidth allocated to the UAV, $P^{\mathrm{UE},tr}$ denotes the transmission power of the UE, which is a constant in this model. σ^2 denotes the variance of Gaussian noise added to the signal during transmission.

We assume that the data size of each packet generated by the user is L_i, so the transmission time between the j-th DP-UAV and the i-th UE can be expressed as:

$$T_{i,j}^{\mathrm{UE},tr}(k) = \frac{L_i}{r_{i,j}(k)}. \tag{12}$$

Therefore, the energy required by the UEs for data transmission is given by:

$$E_{i,j}^{\mathrm{UE},tr}(k) = P_i^{\mathrm{UE},tr} \cdot T_{i,j}^{\mathrm{UE},tr}(k). \tag{13}$$

2) Communication between the BS and the DP-UAVs: We assume that the frequency band on which the DP-UAVs communicate with the BS is different from the ones with the UEs, which means that there is no interference between different communication process of the DP-UAVs. Hence, the transmission rate between the DP-UAV j and the BS can be expressed by:

$$r_{j,\mathrm{BS}} = B_b \log_2 \left(1 + \frac{h_{j,\mathrm{BS}} P_j^{\mathrm{DP},tr}}{\sigma^2}\right), \tag{14}$$

where B_b is the bandwidth allocated to the BS, h_{BS} is the channel gain between the DP-UAVs and the BS, and $P_j^{\mathrm{DP},tr}$ is the uplink transmission power of the DP-UAV. Since the distance between the remote BS and the UAV is sufficiently large compared to the moving distance of the DP-UAVs, the channel gain $h_{j,\mathrm{BS}}$ can be considered as a constant which is determined by the distance between the service area and the BS []. Supposed that in a single time slot, the data of different UEs can be transmitted in parallel using the OFDM technology to the BS. Hence, the time required to transmit the data generated by the i-th UE from the j-th DP-UAV to the BS of is given by:

$$T_j^{\mathrm{DP},tr} = \frac{L_i}{r_{j,\mathrm{BS}}}, \tag{15}$$

and the fronthaul transmission energy of the DP-UAV is:

$$E_j^{\mathrm{DP},tr} = P_j^{\mathrm{DP},tr} \cdot T_j^{\mathrm{DP},tr}. \tag{16}$$

3) Communication with the DC: In this model, the DP-UAVs connect to the DC with the help of the satellite, and the BS are connected via wired fiber link to the DC. Noted that the data size of computing results is sufficiently small compared to the offloading data, so the communication time with the DC can be ignored.

D. AoI model

E. Problem formulation

IV. RS-DRL BASED ALGORITHM

A. RS Based MDP Formulation

1) ***State space*** *$\mathcal{S}$:*

2) ***Action space*** *$\mathcal{A}$:*

3) ***State transition probability*** *$\mathcal{P}$:*

4) ***Reward*** *$\mathcal{R}$:*

B. Proposed DRL algorithm

V. SIMULATION RESULTS

VI. CONCLUSION

REFERENCES

[1] A. Al-Hourani, S. Kandeepan, and S. Lardner, "Optimal lap altitude for maximum coverage," *IEEE Wireless Communications Letters*, vol. 3, no. 6, pp. 569–572, 2014.

[2] X. Lu, W. Yang, S. Yan, Z. Li, and D. W. K. Ng, "Covertness and Timeliness of Data Collection in UAV-Aided Wireless-Powered IoT," *IEEE Internet of Things Journal*, vol. 9, no. 14, pp. 12 573–12 587, Jul. 2022, conference Name: IEEE Internet of Things Journal.