Bandwidth Resource Allocation and Uplink Optimization in MEC System Based on Multi-UAV Collaboration

Na Yu and Xuehe Wang(✉)

School of Artificial Intelligence, Sun Yat-sen University, Zhuhai 519082, China
`yuna25@mail2.sysu.edu.cn`, `wangxuehe@mail.sysu.edu.cn`

Abstract. Unmanned aerial vehicle (UAV) assisted mobile edge computing (MEC) has emerged as a promising solution to improve the performance of communication systems. In order to make use of UAVs to improve the performance of communication systems, this paper proposes an iterative optimization algorithm to meet the communication quality of mobile devices (MDs) in a multi-UAV-assisted MEC system under emergency situations. The algorithm jointly optimizes the number and deployment of UAVs in the system, the selection strategy of MD access links and the bandwidth allocation of each channel, so as to maximize the uplink transmission rate of all MDs in the entire communication system, as well as identify and cover isolated MDs. Through improved clustering algorithm and linear programming, the optimization problem is solved to maximize the uplink rate of the system. Finally, extensive evaluation results show that our proposed framework has superior performance.

Keywords: Mobile edge computing · UAV · Resource allocation

1 Introduction

With the development of the Internet of Things, more and more terminal applications have increasingly demanding requirements for processing efficiency [1]. However, limited battery budgets and computing resources make it difficult for mobile devices (MDs) to accomplish tasks in limited time [2]. Although the transfer of computing tasks to a centralized base station (BS) can relieve the pressure of local computing to a certain extent, it also leads to high latency and network congestion for data transmission [3].

In order to improve the transmission efficiency, mobile edge computing (MEC) has been applied as one of the main technologies to push powerful computing power to the wireless access network [4]. However, fixed MEC servers are not flexible enough to meet the needs of all ground MDs, especially those located at the edge of the communication area, resulting in excessive energy consumption in data transmission [5]. Moreover, in the case of emergency communication, such as densely populated areas, crowded stadiums, earthquake and

V. C. M. Leung et al. (Eds.): Qshine 2023, LNICST 574, pp. 471–483, 2024.
https://doi.org/10.1007/978-3-031-65123-6_35

disaster emergency situations, higher demands on computing power and bandwidth are required [6]. To solve this problem, unmanned aerial vehicles (UAVs) equipped with computing servers are utilized to rapidly provide emergency communication services on demand [7].

In recent years, UAVs have attracted a lot of attention from researchers because of their mobility, flexibility, and maneuverability [8]. Therefore, the use of MEC-enabled UAVs is a promising approach that brings a wealth of advantages over typical ground MEC scenarios due to its ability to connect to ground network terminals and flexible deployment [9]. The authors in [10] studied a 3D UAV-assisted MEC system for mobile user computing offloading, and introduced an active deep reinforcement learning scheme to maximize the expected long-term computing performance of the network by modeling the random game between mobile users. In [11], the authors studied a single-UAV-assisted MEC system, which jointly optimizes task offloading decisions, task allocation, and UAV trajectory to minimize the total energy consumption of the system. [12,13] studied the communication computing resource allocation management of user equipment and UAV trajectory optimization. The authors in [14] maximized the energy efficiency of UAVs by optimally determining the offloading strategy, the transmitted power of ground users, and the flight trajectory of UAVs.

Existing studies have fully demonstrated the role of UAVs in wireless communication networks, but few have considered the combined effects of bandwidth allocation and transmission rate of UAV-supported MEC systems. How to make more reasonable use of the performance of UAVs to improve the system performance is still a major challenge. For example, in the emergency communication scenario, MDs may be unevenly distributed with a long distance from the BS and the data transmission delay is relatively high, which cannot meet the harsh requirements of end users. In this paper, we propose a MEC system with multiple UAV-assisted BS to serve emergency communication scenarios and improve the user experience of mobile terminal devices.

The rest of this paper is structured as follows. We present the system model in Sect. 2. Section 3 introduces the problem formulation. Then, the proposed solution approach are provided in Sect. 4. In Sect. 5, we present the numerical experiments and evaluate the performance. We finally conclude the paper in Sect. 6.

2 System Model

In post-disaster scenarios, such as large-scale earthquakes, effective communication becomes critical for facilitating rescue and relief operations. However, traditional single UAV coverage exhibits limitations in terms of restricted flight tracks and limited accessibility to users. Moreover, these emergency communication scenarios are characterized by numerous obstacles, poor channel status, and substantial demand for communication resources. To address these problems, we consider multi-UAV collaboration to assist and enhance communication capabilities in emergency situations.

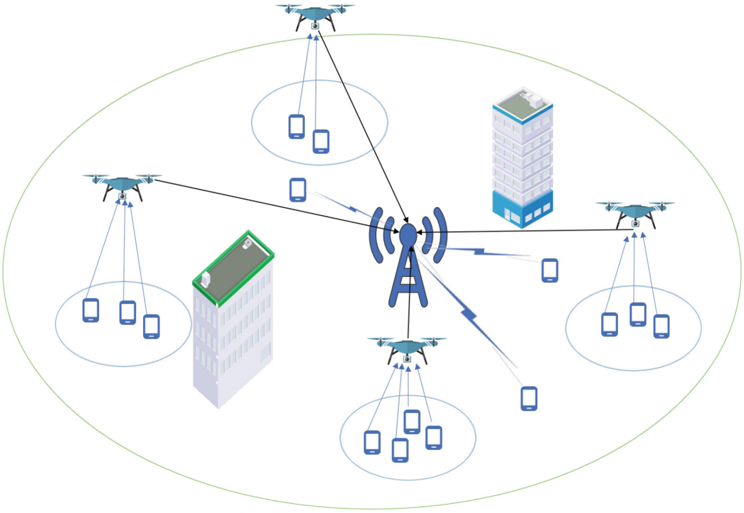

Fig. 1. Multi-UAV-assisted MEC system.

In our work, we consider the MEC system of multiple UAVs working together as shown in Fig. 1. There is one ground BS and U UAVs in the system, where the UAV set is denoted as $\mathcal{U} = \{u_1, u_2, ...u_U\}$. The BS in the system is located in the regional center, serving S MDs, which is denoted as $\mathcal{S} = \{1, 2, ..., S\}$. Each u_i in the system can serve K_i MDs. The set of MDs served by u_i is denoated as $\mathcal{K}_i = \{u_{i,1}, ...u_{i,K_i}\}$. It is assumed that in the initialization stage of the system, the BS knows the physical location of the UAVs, and the UAVs know the physical location of MDs within its service range. The number of MDs on the ground is N, where $N = S + \sum_{i \in \mathcal{U}} K_i$.

Set the plane coordinate of the BS as the two-dimensional coordinate origin, the height of the BS as H_B, its coverage radius as R_B, and thus the three-dimensional coordinate of the BS can be expressed as $p_0 = (0, 0, H_B)$. For the UAV hovering in the air, denote its height as H_U, its coverage radius as R_U, and thus the three-dimensional coordinates of each UAV can be expressed as $p_i = (x_i, y_i, H_U), \forall i \in \mathcal{U}$. The three-dimensional coordinates of the ground MD accessing the BS can be expressed as $p_{iB} = (x_{iB}, y_{iB}, 0), \forall i \in \mathcal{S}$. The coordinates of each MD served by the UAV can be expressed as $p_{ij} = (x_{ij}, y_{ij}, 0), \forall i \in \mathcal{U}, \forall j \in \mathcal{K}_i$. The system works in frequency division duplex mode, which is easy to use with strong anti-interference ability. At the same time, the BS and the UAVs are equipped with omnidirectional antennas. The MD who chooses the UAV service must connect to the BS through the UAV, and after the BS is connected to the core network, the data is processed and then transmitted back to the MD.

2.1 MD Access Model

In this system, the ground MD can choose to access the BS directly or through UAV. The access strategies of N MDs are represented by set $\mathcal{G}$, where $\mathcal{G} = \{g_1, g_2, ..., g_N\}$. When $g_i = 0, i \in N$, MD i chooses to access the BS; When $g_i = j, j \in \mathcal{U}$, MD i chooses to access UAV j.

2.2 Communication Model

In the system we consider, there are three types of channel models, i.e., the channel between the MD and the UAV (MD to UAV, M2U), the channel between the UAV and the BS (UAV to BS, U2B), and the channel between the MD and the BS (MD to BS, M2B). In emergency communication scenarios, such as earthquakes and collapse, there will be some large obstacles, which makes the composition of the communication channel more complex. Thus the transmission of wireless signals is composed of line-of-sight transmission and non-line-of-sight transmission. In this study, it is assumed that there are line-of-sight transmission channels and non-line-of-sight transmission channels in both M2U signal transmission and M2B signal transmission. As the UAV flies at a certain height and there are no obvious obstacles between it and the BS, it is assumed that only line-of-sight transmission channels exist in U2B signal transmission. The path loss of line-of-sight transmission and non-line-of-sight transmission is given as follows:

$$L_{los} = \eta_{los} \left(\frac{4\pi f d}{c} \right)^2, \tag{1}$$

$$L_{nlos} = \eta_{nlos} \left(\frac{4\pi f d}{c} \right)^2, \tag{2}$$

where c is the speed of light, d is the distance between the signal transmitter and the signal receiver, f is the carrier frequency, and η_{los} and η_{nlos} are the average additional loss of line-of-sight transmission and non-line-of-sight transmission, respectively. The channel link probability of line-of-sight transmission is shown as follows:

$$O_{los}(\theta) = \frac{1}{1 + \alpha \exp(-\beta[\theta - \alpha])}, \tag{3}$$

where $\theta = sin^{-1}(h/d)$, h is the height of the receiver, d is the linear distance between the transmitter and the receiver, θ is the elevation angle between the transmitter and the receiver, α and β are parameters determined by the communication system environment. The channel link probability of non-line-of-sight transmission is shown as follows:

$$O_{nlos}(\theta) = 1 - O_{los}(\theta). \tag{4}$$

We assume that the total bandwidth resource of the communication system is B with $B = B_{M2B} + B_{M2U} + B_{U2B}$, where B_{M2B} represents the total bandwidth of the signal transmission channel between the MDs and the BS, B_{M2U} represents the total bandwidth of the signal transmission channel between the MDs and the UAVs, and B_{U2B} represents the total bandwidth of the signal transmission channel between the UAVs and the BS.

Since the orthogonal frequency division multiple access (OFDMA) mode is adopted between the BS and the MDs, and the bandwidth resources of the channel are allocated to S MDs, $B_{M2B} = \sum B_{iB}, i \in \mathcal{S}$. As the wireless signal transmission includes line-of-sight transmission and non-line-of-sight transmission, the data transmission rate between the MDs and the BS is given as follows, for $\forall i \in \mathcal{S}$:

$$\gamma_{iB,los} = \frac{P_{iB}}{L_{los}\left(d_{iB}\right)^2 \sigma_B^2}, \tag{5}$$

$$\gamma_{iB,nlos} = \frac{P_{iB}}{L_{nlos}\left(d_{iB}\right)^2 \sigma_B^2}, \tag{6}$$

$$\begin{aligned} C_{iB} = B_{iB}(O_{los}(H_B, d_{iB}) \log_2\left(1 + \gamma_{iB,los}\right) \\ + O_{nlos}\left(H_B, d_{iB}\right) \log_2(1 + \gamma_{iB,nlos})), \end{aligned} \tag{7}$$

where C_{iB} is the data transmission rate between the MD and the BS, and P_{iB} is the transmission power of the MD, $d_{iB} = \sqrt{x_{iB}^2 + y_{iB}^2 + H_B^2}, i \in \mathcal{S}$ is the distance between the MD and the BS, and σ_B^2 is the Gaussian white noise power.

OFDMA is also adopted between each UAV and MDs in its coverage area, and channel bandwidth resources are allocated to $K_i(\forall i \in \mathcal{U})$ MDs, $B_{M2U} = \sum_{i \in \mathcal{U}} B_i, B_i = \sum_{i \in \mathcal{U}, j \in \mathcal{K}_i} B_{ij}$. The wireless signal transmission includes line-of-sight transmission and non-line-of-sight transmission, and the data transmission rate between the UAV and the MD is shown as follows, for $\forall i \in \mathcal{U}, j \in \mathcal{K}_i$:

$$\gamma_{ij,los} = \frac{P_{ij}}{L_{los}\left(d_{ij}\right)^2 \sigma_i^2}, \tag{8}$$

$$\gamma_{ij,nlos} = \frac{P_{ij}}{L_{nlos}\left(d_{ij}\right)^2 \sigma_i^2}, \tag{9}$$

$$\begin{aligned} C_{ij} = B_{ij}(O_{los}(H_B, d_{ij}) \log_2\left(1 + \gamma_{ij,los}\right) \\ + O_{nlos}\left(H_B, d_{ij}\right) \log_2(1 + \gamma_{ij,nlos})), \end{aligned} \tag{10}$$

where C_{ij} is the data transmission rate between the MD and the UAV, and P_{ij} is the transmission power of the MD which connects with the UAV, $d_{ij} = \sqrt{\left(x_i - x_{ij}\right)^2 + \left(y_i - y_{ij}\right)^2 + H_U^2}, \forall i \in \mathcal{U}, j \in \mathcal{K}_i$ is the distance between the MD and the UAV, and σ_i^2 is the Gaussian white noise power.

The OFDMA mode is also adopted between the BS and each UAV, and the channel bandwidth resource is allocated to U UAVs, $B_{U2B} = \sum_{j \in \mathcal{U}} B_j$. Since wireless signal transmission only includes line-of-sight transmission in U2B signal transmission, the data transmission rate between the BS and each UAV is as follows, for $\forall j \in \mathcal{U}$:

$$\gamma_{Bj} = \frac{P_{Bj}}{L_{los}\left(d_{Bj}\right)^2 \sigma_i^2}, \tag{11}$$

$$C_{Bj} = B_j \log_2 \left(1 + \gamma_{Bj}\right). \tag{12}$$

The uplink transmission rate of the MD to the BS is expressed as $C_{iB}, \forall i \in \mathcal{S}$, and the uplink transmission rate of the MD covered by each UAV is expressed as $\widetilde{C}_{ij}, \forall i \in \mathcal{U}, j \in \mathcal{K}_i$. The MD accessing the UAV first uploads the signal to the UAV, and then the UAV uploads it to the BS. Therefore, $\widetilde{C}_{ij}$ is actually the lower uplink transmission rate between the MD and the UAV and the uplink transmission rate between the UAV and the BS, $\widetilde{C}_{ij} = min(C_{Bj}, C_{ij})$, $\forall i \in N/\mathcal{S}, j \in \mathcal{U}$.

3 Problem Formulation

Since each MD in the system has a basic uplink rate requirement of C_{min} in emergency communication scenarios, the optimization goal is to maximize the sum of the uplink transmission rates of all MDs, and the optimization variables include (1) the number of UAVs U; (2) UAV distribution coordinates p_i; (3) MD access link selection policy $\mathcal{G}$; (4) System bandwidth resource allocation scheme a_i. The specific problems and related constraints are as follows:

$$\mathcal{P}_1 : \max_{U,\mathcal{G},\{p_i,\forall i\in\mathcal{U}\},\{a_i,\forall i\in\mathcal{U}+\mathcal{N}\}} \sum_{i\in\mathcal{U}} \sum_{j\in\mathcal{K}_i} \widetilde{C}_{ij} + \sum_{i\in\mathcal{S}} C_{iB}, \tag{13}$$

$$\text{s.t.} \quad B = B_{M2B} + B_{M2U} + B_{U2B}, \tag{13a}$$

$$B_{M2B} = \sum_{i\in\mathcal{S}} B_{iB}, \tag{13b}$$

$$B_{M2U} = \sum_{i\in\mathcal{U}} B_i = \sum_{i\in\mathcal{U},j\in\mathcal{K}_i} B_{ij}, \tag{13c}$$

$$B_{U2B} = \sum_{j\in\mathcal{U}} B_j, \tag{13d}$$

$$\widetilde{C}_{ij} \geq C_{\min}, \forall i \in \mathcal{U}, \forall j \in \mathcal{K}_i, \tag{13e}$$

$$C_{iB} \geq C_{\min}, \forall i \in \mathcal{S}. \tag{13f}$$

where (13a)–(13d) is a constraint on the system bandwidth resources, the sum of the bandwidth resources of the three channels (i.e., M2B, M2U and U2B) is the bandwidth resources of the whole system, and the sum of the channel bandwidth of each ground MD accessing the UAV is the bandwidth resources allocated to each UAV. (13e)–(13f) is a constraint on the uplink transmission rate of each MD, which needs to meet the user communication experience of each MD.

It can be seen from the constructed optimization problem that the uplink transmission rate of all MDs is linearly related to the transmission channel bandwidth a_i. In addition, for a given variable a_i, the optimization problem can be regarded as a clustering problem with respect to variables U, p_i and $\mathcal{G}$. The specific algorithm design will be introduced in the next section.

4 Solution Approach

Since the objective optimization problem $\mathcal{P}_1$ is a complex linear programming problem with cluster categorical variables $\mathcal{G}$ and U, continuous variables $p_i, \forall i \in \mathcal{U}$, and $a_i, \forall i \in \mathcal{N} + \mathcal{U}$, the original problem can be decomposed into three subproblems. Firstly, cluster classification of MDs is carried out to identify isolated MDs. Then, we solve the sub-problems of the corresponding variables while keeping the related variables unchanged, so as to maximize the sum of the uplink transmission rates of MDs which can also reduce the complexity of the algorithm. In order to obtain reasonable results, an iterative optimization algorithm is proposed in this section. The details of the algorithm are as follows.

4.1 UAV Number and MD Clustering Optimization Algorithm

Each UAV is allowed to access several MDs at the same time, and adopting the OFDMA mode can reduce the signal interference between MDs during data transmission while ensuring the quality of channel signal transmission in emergency communication scenarios. MDs can be reasonably grouped by clustering algorithm, so as to allocate the UAVs and the required bandwidth resources, and determine the isolated MDs in the system. However, traditional clustering algorithms, such as K-means, cannot cluster without knowing the number of clusters. Therefore, we use density-based spatial clustering of applications with noise (DBSCAN) to cluster MDs and identify isolated MDs, and then the selection policy of MD access link $\mathcal{G}$ is obtained.

In the DBSCAN clustering algorithm, a set of parameters is used to describe the tightness of the data set, which can be expressed as $(\epsilon, MinPts)$, where ϵ describes the neighborhood distance threshold of a certain data. $MinPts$ describes the smallest number of neighborhoods in which the Euclidean distance of some data is ϵ. By using the DBSCAN clustering algorithm, we obtain the number of UAVs U required in the communication system, the clustering of MDs $Z = \{Z_1, Z_2, ..., Z_U\}$ and the isolated collection of MDs $\{\mu_j\}$.

4.2 UAV Position Optimization Algorithm

When the number of UAVs U, bandwidth resource allocation scheme $a_i, \forall i \in \mathcal{N} + \mathcal{U}$ and MD access link selection strategy $\mathcal{G}$ are fixed, subproblem $\mathcal{P}_2$ is a complex convex optimization problem about UAVs distribution coordinates $p_i, \forall i \in \mathcal{U}$:

$$\mathcal{P}_2 : \max_{\{p_i, \forall i \in \mathcal{U}\}} \sum_{i \in \mathcal{U}} \sum_{j \in \mathcal{K}_i} \widetilde{C}_{ij} + \sum_{i \in \mathcal{S}} C_{iB}, \tag{14}$$
$$\text{s.t.} \quad (13e) - (13f).$$

To obtain the distributed coordinates p_i of UAVs, we propose an improved K-means central clustering algorithm. First, the position coordinates of each

UAV are randomly initialized. The coordinate range is the area covered by the UAV. Second, the uplink rate of the MD served by the UAV is calculated and multiplied by the coordinates of the UAV as a weight coefficient. Third, calculate and update the position coordinates of the UAV. Finally, repeat the above steps until the position coordinates of each UAV do not change after each generation.

4.3 System Bandwidth Resource Allocation Algorithm

To obtain the system bandwidth resource allocation scheme a_i, we propose the optimization of the subproblem $\mathcal{P}_3$. When the number of UAVs U, the selection strategy of MD access link $\mathcal{G}$ and the distribution coordinate of UAVs p_i are fixed, the subproblem $\mathcal{P}_3$ is a linear programming problem of the system bandwidth resource allocation scheme a_i. The maximum problem $\mathcal{P}_3$ can be converted to the minimum problem $\mathcal{P}_{3.1}$, with the correlation coefficients in the target problem turned negative. Finally, we utilize the convex optimization tool OPTI to solve the problem.

$$\begin{aligned} \mathcal{P}_3: \max_{\{a_i, \forall i \in \mathcal{U}+\mathcal{N}\}} & \sum_{i\in\mathcal{U}} \sum_{j\in\mathcal{K}_i} \widetilde{C}_{ij} + \sum_{i\in\mathcal{S}} C_{iB}, \\ \text{s.t.} \quad & (13a) - (13f). \end{aligned} \tag{15}$$

$$\mathcal{P}_{3.1}: \min_{\{a_i, \forall i \in \mathcal{U}+\mathcal{N}\}} -(\sum_{i\in\mathcal{U}} \sum_{j\in\mathcal{K}_i} \widetilde{C}_{ij} + \sum_{i\in\mathcal{S}} C_{iB}) \tag{16}$$

4.4 Algorithm Design and Complexity Analysis

According to the above analysis of solving the number of UAVs U, the selection strategy of MD access link $\mathcal{G}$, the position coordinates of each UAV $p_i, \forall i \in \mathcal{U}$, and the system bandwidth resource allocation scheme $a_i, \forall i \in \mathcal{U} + \mathcal{N}$, an algorithm for solving the original problem $\mathcal{P}_1$ is proposed as shown in Algorithm 1.

In the UAV number and MD clustering optimization algorithm, the computational complexity is mainly concentrated in the DBSCAN clustering, with the time complexity $O(N\tau)$, where τ is the time required to find the points in the ϵ neighborhood that meet the requirements of the minimum number of $MinPts$ included. The time complexity in the worst case is $O(N^2)$. However, if a specific data structure, such as KD tree, is used to efficiently search and query the two-dimensional plane coordinates of MDs by obtaining all points within a given distance of a specific point, the time complexity can be reduced to $O(NlogN)$. The spatial complexity of the algorithm is $O(N)$, and each data point only needs to maintain the cluster label and the identification of each point, including the core point, noise point, or boundary point. In the UAV position optimization algorithm, its complexity is mainly concentrated in the traversal cycle of updating the cluster center, which is $O(UnkND)$, where n is the number of iterations required when updating the cluster center, D is the dimension of the data point,

Algorithm 1. Bandwidth resource allocation and uplink optimization algorithm in MEC system based on multi-UAV cooperation.

```
Input: Ground MD coordinate dataset Data = $\{p_i = (x_i, y_i, 0), \forall i \in \mathcal{N}\}$, UAV flight altitude $H_U$, system bandwidth resource allocation coefficient $\{a_i^{(0)}, \forall i \in \mathcal{U} + \mathcal{N}\}$, convergence error $\delta$, iteration times $r$, maximum iteration times $R$;
Output: The sum of uplink transmission rates of all MDs in the communication system $C_{total}$, the number of UAVs $U$, the position coordinates of each UAV $\{p_i, \forall i \in \mathcal{U}\}$, the selection strategy of MD access link $\mathcal{G}$, the system bandwidth resource allocation scheme $\{a_i, \forall i \in \mathcal{U} + \mathcal{N}\}$;
1: With the given Data = $\{p_i = (x_i, y_i, 0), \forall i \in \mathcal{N}\}$, obtain $U$ and $\mathcal{G}$ by UAV number and MD clustering optimal algorithm;
2: With the given $\{a_i^{(r)}, \forall i \in \mathcal{U} + \mathcal{N}\}$, obtain $\{p_i^{(r+1)}, \forall i \in \mathcal{U}\}$ by UAV position optimization algorithm;
3: With the given $\{p_i^{(r+1)}, \forall i \in \mathcal{U}\}$, obtain $\{a_i^{(r+1)}, \forall i \in \mathcal{U} + \mathcal{N}\}$ by system bandwidth resource allocation algorithm;
4: Calculate $C_{total}^{(r+1)} = \sum_{s \in \mathcal{S}} C\left(\mathcal{G}, U, \left\{p_i^{(r+1)} \mid \forall i \in \mathcal{U}\right\}, \left\{a_i^{(r+1)} \mid \forall i \in \mathcal{U} + \mathcal{N}\right\}\right)$. If $\left|C_{\text{total}}^{(r+1)} - C_{\text{total}}^{(r)}\right| \leq \delta$, or $r \succ R$, terminate. Otherwise, $r = r + 1$, and go to step 2;
5: return $C_{total}$.
```

k is equal to 1. n and D are generally regarded as constants, so the time complexity can be simplified to $O(UN)$; The spatial complexity of the algorithm is $O(UD(N+k))$, which can be simplified to $O(U(N+1))$. In the system bandwidth resource allocation algorithm, its complexity is mainly concentrated on solving linear programming problems with OPTI tools, which is generally acceptable. In addition, the convergence of Algorithm 1 is easy to prove according to the loop from steps 2 to 4.

5 Simulation Results

In this section, we will analyze the performance of the system bandwidth resource allocation and uplink link optimization algorithm in the MEC system based on multi-UAV cooperation. Note that the MDs are not uniformly distributed. In order to verify the performance of the proposed scheme, two comparison schemes about the distribution of UAVs are set up, respectively: (1) In the communication system, the uniform distribution of UAVs is named Scheme 1, and (2) the UAVs are grouped and located according to the K-means clustering algorithm, named Scheme 2. In addition, the general parameters are set as: H_B = 30 m, R_B = 300 m, H_U = 50 m, R_U = 20 m, B = 80 MHz, σ^2 = -70 dBm/Hz, P = 1W, η_{los} = 2, η_{nlos} = 20, f = 2 GHz, $c = 3\times 10^8$ m/s, C_{min} = 1 Mbps, $\alpha = 5$ and $\beta = 0.2$ [15–17], and other parameters are alternative in the various scenarios.

Figure 2 depicts the variation of the total uplink transmission rate of MDs with the number of iterations under different UAV distribution schemes. In Scheme 1, the number of UAVs is determined by the optimization algorithm

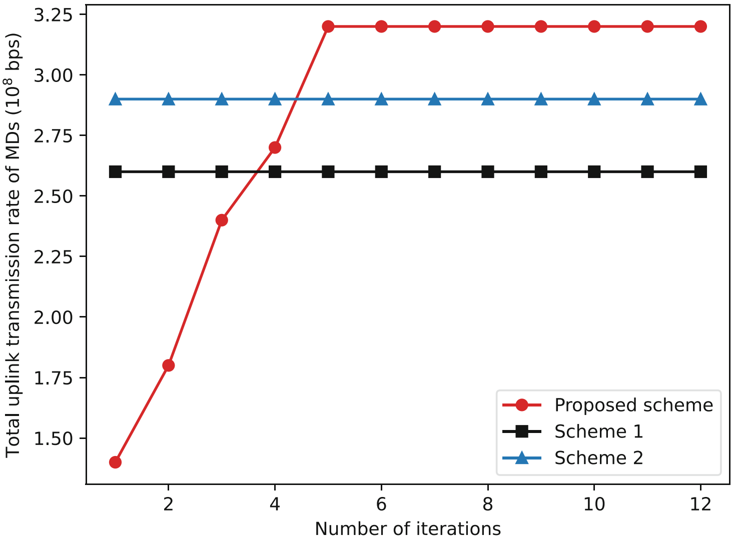

Fig. 2. The total uplink transmission rate of MDs with the number of iterations under different UAV distribution schemes.

of the number of UAVs proposed in this paper with the UAVs uniformly distributed, and the simulation results show that under this scheme, the total uplink transmission rate of the system is minimum. As the uniform distribution of UAVs is the simplest and most time-saving in operation, it does not consider the actual channel state, resulting in a waste of bandwidth resources, and even in some cases can not meet the needs of all MDs for communication quality. The number of UAVs adopted in scheme 2 is consistent with that of our proposed scheme, with the total uplink transmission rate slightly lower than that of our proposed scheme. As k-means is a partition-based clustering algorithm, the number of clusters K needs to be specified, and the initial clustering center often has a great impact on the clustering results. Although the time complexity of the algorithm is relatively small, the clustering effect is poor, and noise points cannot be directly identified. It can be seen that the scheme proposed in this paper can well cope with the communication problem that MDs are densely partitioned and contain multiple isolated MDs in emergency communication scenarios, so as to improve the total uplink transmission rate of the entire system and ensure the basic communication quality.

Figure 3 depicts the variation of the total uplink transmission rate of MDs with the number of iterations under different bandwidth resource allocation schemes. We set up two comparison schemes, which are (a) distributing system bandwidth resources evenly to each communication channel; (b) The bandwidth resource allocated by the M2U channel of the UAV is equal to the total channel bandwidth of the MDs accessing the link. The simulation results show that the average bandwidth allocation method of Scheme a is not applicable

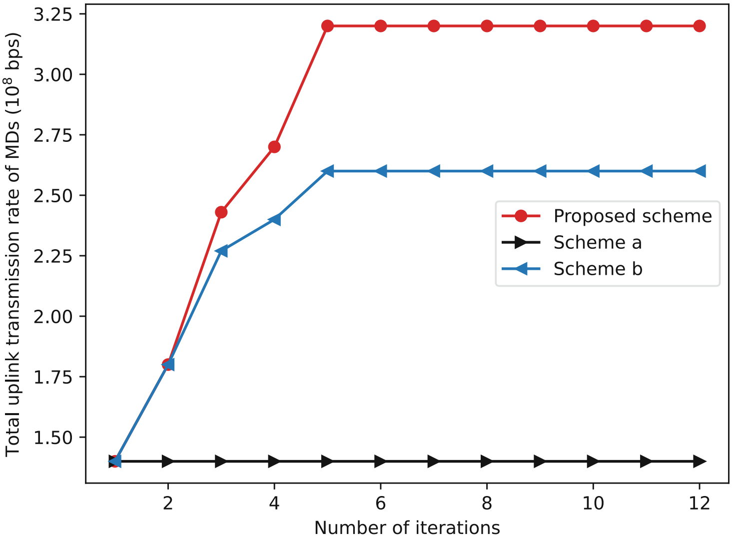

Fig. 3. The total uplink transmission rate of MDs varies with the number of algorithm iterations under different bandwidth resource allocation schemes.

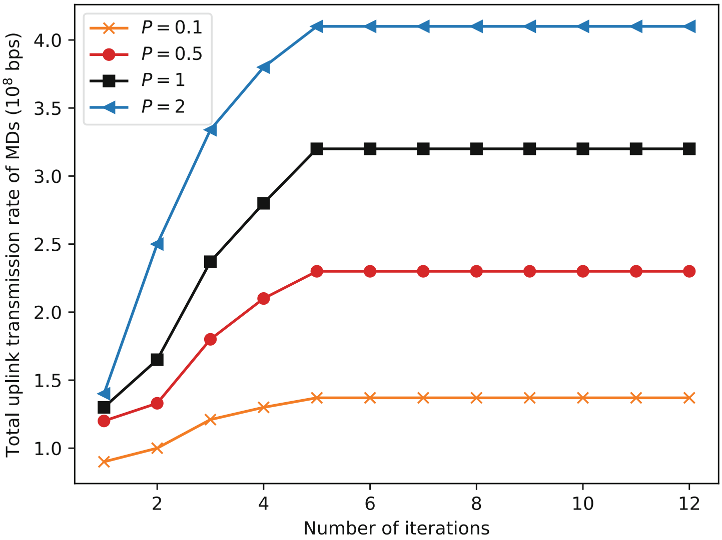

Fig. 4. The total uplink transmission rate of MDs varies with the number of algorithm iterations under different transmitting powers.

in this emergency communication scenario. This is because evenly distributing bandwidth resources causes MD far from the BS, which is unable to achieve the most basic user experience. The performance of Scheme b is much better than that of Scheme a. However, as the bandwidth resources of all channels are not optimized and the uplink rate of MDs is the lower value of the transmission rate of M2U and U2B channels of the terminal device, some channel bandwidth resources are wasted and cannot be properly allocated to MDs with poor channel status. By considering the above issues, the scheme proposed in this paper can greatly improve the total uplink transmission rate in the emergency communication scenario while satisfying the user experience of each MD. As shown in Fig. 3, the performance of our proposed scheme is better than the above two schemes. At the same time, it guarantees communication quality and covers all terminal devices, including isolated devices, which improves the performance of the entire MEC system.

Figure 4 describes the variation of the total uplink transmission rate of MDs with the number of algorithm iterations under different transmit power. The transmitted power of MD is 0.1W, 0.5W, 1W, and 2W, respectively. The simulation results show that the uplink transmission rate of the entire system increases with the MD's transmission power. In the emergency communication scenario, the communication quality of MD is related to its own energy such as electric energy. Only when the MD can transmit information to the BS with a certain transmit power can the basic user communication experience be guaranteed and the system performance of the entire wireless communication network be improved.

6 Conclusion

In this paper, we study the resource allocation problem of the multi-UAV-assisted MEC system in emergency communication scenarios. From the perspective of MDs, we discuss the problem of maximizing the total data transmission rate of MDs in the system, namely the total uplink transmission rate, and optimize the access link strategy of MDs, the distribution strategy of UAVs and the bandwidth resource allocation strategy of the system. In order to maximize the total data transmission rate of all MDs, satisfy the basic user communication experience, and cover the isolated points in the wireless communication network, the system bandwidth resource allocation and uplink link optimization algorithm based on multi-UAVs cooperation communication system are proposed. Numerical experiment results show that the proposed scheme can improve the total data transmission rate of MDs, meet the user communication experience, and make the system performance better. At the same time, the selected density-based clustering algorithm can effectively cluster the MDs in the system and distinguish isolated points.

References

1. Mao, Y., You, C., Zhang, J., Huang, K., Letaief, K.B.: A survey on mobile edge computing: the communication perspective. IEEE Commun. Surv. Tutor. **19**(4), 2322–2358 (2017)
2. Zhu, T., Shi, T., Li, J., Cai, Z., Zhou, X.: Task scheduling in deadline-aware mobile edge computing systems. IEEE Internet Things J. **6**(3), 4854–4866 (2019). https://doi.org/10.1109/JIOT.2018.2874954

3. Pang, X., Tang, J., Zhao, N., Zhang, X., Qian, Y.: Energy-efficient design for mmwave-enabled noma-uav networks. Sci. China Inf. Sci. **64**, 1–14 (2021)
4. Siriwardhana, Y., Porambage, P., Liyanage, M., Ylianttila, M.: A survey on mobile augmented reality with 5G mobile edge computing: architectures, applications, and technical aspects. IEEE Commun. Surv. Tutor. **23**(2), 1160–1192 (2021)
5. Ye, Y., Hu, R.Q., Lu, G., Shi, L.: Enhance latency-constrained computation in mec networks using uplink noma. IEEE Trans. Commun. **68**(4), 2409–2425 (2020). https://doi.org/10.1109/TCOMM.2020.2969666
6. Jiang, F., Wang, K., Dong, L., Pan, C., Xu, W., Yang, K.: Ai driven heterogeneous mec system with uav assistance for dynamic environment: challenges and solutions. IEEE Netw. **35**(1), 400–408 (2021). https://doi.org/10.1109/MNET.011.2000440
7. Xu, J., Ota, K., Dong, M.: Big data on the fly: UAV-mounted mobile edge computing for disaster management. IEEE Trans. Netw. Sci. Eng. **7**(4), 2620–2630 (2020)
8. Liu, B., Wan, Y., Zhou, F., Wu, Q., Hu, R.Q.: Resource allocation and trajectory design for miso UAV-assisted mec networks. IEEE Trans. Veh. Technol. **71**(5), 4933–4948 (2022)
9. Javaid, S., et al.: Communication and control in collaborative UAVs: recent advances and future trends. IEEE Trans. Intell. Transport. Syst. (2023)
10. Chen, X., Chen, T., Zhao, Z., Zhang, H., Bennis, M., Yusheng, J.: Resource awareness in unmanned aerial vehicle-assisted mobile-edge computing systems. In: 2020 IEEE 91st Vehicular Technology Conference (VTC2020-Spring), pp. 1–6. IEEE (2020)
11. Guo, H., Liu, J.: UAV-enhanced intelligent offloading for internet of things at the edge. IEEE Trans. Ind. Inf. **16**(4), 2737–2746 (2019)
12. Tun, Y.K., Park, Y.M., Tran, N.H., Saad, W., Pandey, S.R., Hong, C.S.: Energy-efficient resource management in UAV-assisted mobile edge computing. IEEE Commun. Lett. **25**(1), 249–253 (2021). https://doi.org/10.1109/LCOMM.2020.3026033
13. Alsenwi, M., Tun, Y.K., Pandey, S.R., Ei, N.N., Hong, C.S.: UAV-assisted multi-access edge computing system: an energy-efficient resource management framework. In: 2020 International Conference on Information Networking (ICOIN), pp. 214–219. IEEE (2020)
14. Li, M., Cheng, N., Gao, J., Wang, Y., Zhao, L., Shen, X.: Energy-efficient UAV-assisted mobile edge computing: resource allocation and trajectory optimization. IEEE Trans. Veh. Technol. **69**(3), 3424–3438 (2020)
15. Hu, X., Wong, K.K., Yang, K., Zheng, Z.: UAV-assisted relaying and edge computing: scheduling and trajectory optimization. IEEE Trans. Wirel. Commun. **18**(10), 4738–4752 (2019). https://doi.org/10.1109/TWC.2019.2928539
16. Hua, M., Wang, Y., Li, C., Huang, Y., Yang, L.: Energy-efficient optimization for UAV-aided cellular offloading. IEEE Wirel. Commun. Lett. **8**(3), 769–772 (2019). https://doi.org/10.1109/LWC.2019.2891727
17. Ndikumana, A., et al.: Joint communication, computation, caching, and control in big data multi-access edge computing. IEEE Trans. Mob. Comput. **19**(6), 1359–1374 (2020). https://doi.org/10.1109/TMC.2019.2908403