Journal of Computers Vol. 35 No. 3, June 2024, pp. 81-94
doi: 10.53106/199115992024063503007

Stable User Association of UAV-assisted Network: A Two-levels Matching with Cyclic Preferences based Approach

Zhong-Yu Ma[1], Kai-Ran Chen[2*], Qun Guo[3], Ze-Sen Wang[4]

[1] Dunhuang Academy, Lanzhou, Gansu, China
mazybg@nwnu.edu.cn

[2] Department of Computer Science and Engineering, Northwest Normal University,
Lanzhou, Gansu, China
2021222187@nwnu.edu.cn

[3] College of Electrical and Information Engineering, Lanzhou University of Technology,
Lanzhou, Gansu, China
guoqun@lut.edu.cn

[4] Department of Computer Science and Engineering, Northwest Normal University,
Lanzhou, Gansu, China
202131607330@nwnu.edu.cn

Received 8 September 2023; Revised 6 January 2024; Accepted 2 February 2024

Abstract. Due to the development of the 6th generation (6G) network, the integrated ground and air emergency communication system has an important impact on ensuring stable and efficient feedback links in major events and emergencies. Ground base stations (GBSs) and unmanned aerial vehicles (UAVs) and are key components of the air-ground network, providing access services for mobile Internet of Things (IoT) users. In this work, the cooperation between GBSs and UAVs is considered to achieve user matching problems in UAV-assisted air-ground networks, which can be described as a mixed integer nonlinear programming problem. Due to the difficulty of obtaining the best solution through exhaustive search in largescale networks, a GBS-oriented matching algorithm is proposed to handle the user association between the user, UAV and GBS. A restricted two-levels matching based approach with cyclic preferences (R-TMUA) is implemented to obtain stable solutions. In addition, to improve the efficiency of the algorithm model and reduce redundancy, this article proposes two bilateral matching algorithms, which consist of a user-UAV matching algorithm based on Gale-Shapley (GS) and a UAV-GBS matching algorithm based on random path to pair stable (RPPS). The simulation results demonstrate that the proposed algorithm outperforms traditional user matching schemes and has the capability to accommodate a greater number of users compared to conventional methods.

Keywords: UAV-assisted air-ground network, dynamic resource allocation, emergency communication

1 Introduction

The development prospects and key technologies of the 6th Generation Mobile Communication Technology (6G) have become a new research hotspot globally [1]. One of the design goals of 6G is to provide ubiquitous network access services for mobile Internet of Things (IoT) users, achieving seamless coverage worldwide [2, 3]. In recent years, some natural disasters and emergencies have posed more severe challenges to traditional ground emergency communication systems. The traditional ground emergency communication system will not be able to deal with emergencies in time and effectively [4]. UAVs, with their high flexibility, low cost, and strong functionality, can effectively guarantee the communication needs of ground mobile users in emergency scenarios [5, 6]. Due to the low loss and delay of transmission in low-orbit satellites, and the ability to form constellations to achieve seamless global coverage, it has been applied as a return link in practical systems. The integration of UAVs, satellites, and ground networks into a space-air-ground integrated network can not only provide emergency coverage when GBSs are damaged, but also provide supplementary coverage for remote mountainous areas, open seas, and other areas, as well as diverting business traffic from hotspots, which has become a typical networking method for 6G [7]. The UAV-assisted emergency communication system and its key technologies have

* Corresponding Author

been widely concerned.

Space-air-ground integrated networks (SAGIN) can provide three-dimensional network connection for UAVs anytime and anywhere, which has become the key research direction of the next generation [8]. Recently, the mTenna equipped with Toyota's Mirai car can provide it with a transfer rate of 50*MB/s*. Google and Facebook also plan to deploy balloons and unmanned aerial vehicles (UAVs) to provide Internet services in remote areas, respectively [9]. However, the received data in UAVs still need to be back to ground, but building specialized ground stations for GBSs is prohibitive or even impossible due to the geographical factors [10]. The ideal channels between UAVs and LEO satellites are good choices to serve as backhauls for UAVs. Further, LEO satellite networks are worldwide connected and can guarantee the collected data back to earth in an acceptable time [11].

There are some recent researches on UAVs. M. D. Zakaria et al. [12] studied a phased array antenna method to enhance the HAP system capacity. T. Hong et al. [13] put forward a broad network composed of HAP and low Earth orbit (LEO), which were employed to offer network services for remote area users. S. Yan et al. [14] studied the ground user entry, which analyzed examined the user competition and the decision-making process between UAV and satellite in emergency situations. Yuan. Z et al. [15] jointly optimized the UAV's trajectory and users' association to reduce interference. Shakhatreh Majd [16] addressed these challenges including data rate, SINR, and bandwidth constraints in the joint UAV trajectory and user association problem. Sun Xiang [17] formulate the problem of jointly optimizing the GBS trajectory and user association in the UAV-assisted mobile networks. Chunyu Pan [18] proposed an algorithm that optimizes the trajectory of UAVs and the association of users in future software-defined cellular network (SDCN).

User association, which improving the network performance by optimizing the user's access network, has become the top priority in the field of integrated network research. Ruan [19] proposed the issue of spectrum efficiency between satellite networks and ground networks. The author proposed an adaptive transmission scheme with symbol error rate (SER) constraints H. Zhang [20] designed an algorithm utilize a many-to-many matching game approach to address the pairing challenges on the Internet of Things network system. Z. Miao [21] adopted a distributed suboptimal algorithm based on trilateral matching to derive an optimal solution among content, computing nodes, mobile virtual network operators and users. Samar Shaker Metwaly [22] proposed a learning algorithm based on matching games and no-regret learning, employing NOMA pairing at each GBS to maximize the overall system rate and capacity. X. Huang [23] focused on a single-cell multi-user massive MIMO system. Das Deepa [24] explored a framework that combines matching game theory with machine learning techniques. Although there has been some research work on UAV assistance before, the solution based on matching game [25] to provide stable service for users in emergency areas has not been studied before.

In response to the above literature, this chapter considers the user association problem with the assistance of drones for high-capacity hotspots. Considering the limited resources, diverse and competitive demands of the space-ground integrated network, as well as the different values of data for different users, and the different costs that these users are willing to pay to the GBS's network for data uploading.

In this article, the problem of emergency communication that arises from major events and shares the network communication pressure in hotspot areas are considered, such as the Olympics, where there may be insufficient network information service capabilities or ground base stations are accidentally damaged. The problem aims to maximize the GBS's received revenue (total data priority) as high-priority users are more likely to provide more important information and pay more for UAV and GBS services. In addition, the relative variation between ground users and UAV is small and can be ignored. Since it is NP-hard [26], solving the problem directly in MINLP form is still difficult. In summary, the main contributions of this paper can be outlined as follows:

- In the UAV-assisted emergency communication system, the overall emergency handling efficiency is improved by optimizing the user association and maximizing the benefits of the GBS. Specifically, high-priority users can achieve network information interaction by directly connecting to GBSs, and low-priority users which carry delay-tolerant data is transmitted to GBSs through UAVs.
- Inspired by the matching game theory, the relationship problem between the three agents (users, UAVs, and ground base stations) can be re-expressed as a three-party matching game, where the agents have size and cyclic preference lists (TMUA). The goal of TMUA is to find a stable match between users, UAVs, and ground base stations. To effectively obtain the stable matching results of the TMUA problem, we propose the Restricted Three-Sided Matching Game for Ground Base Stations (R-TMUA) algorithm by adding two additional conditions to the preference lists of GBS and UAVs.
- In each time slot, the algorithm fails to maintain the stable matching achieved in the previous time slot. Re-executing an R-TMUA algorithm is somewhat redundant and wasteful of time, the GS matching algorithm-based solution is designed to achieve the matching between users and UAVs [27].

- Due to the large coverage of UAVs, the relationship between users and UAVs can last for a long time until the users' requirement change, the RPPS matching algorithm-based solution is proposed to achieve dynamic multi-to-multi matching between UAVs and GBSs [28].

The rest of this paper can be outlined as follows. The network scenario and problem formulation are demonstrated in Section II. The GBS-Oriented two-levels Matching Algorithm are introduced respectively in Section III. The simulation results and analysis of a two-levels matching algorithm are given in Section IV. In the end, the paper is summarized in Section V.

2 System Model

A UAV-assisted emergency communication scenario is constructed in subsection 2.1. Then the UAV channel budget for millimeter wave communication is given in subsection 2.2. Finally, the problem formulation is constructed in subsection 2.3. The key notations used in this article are listed in Table 1.

2.1 System Overview

An Olympic air-ground network scenario including GBSs, UAVs and users is shown in Fig. 1. The scenario considered in this paper is that if it is insufficient to support hotspot high-capacity scenarios, it is necessary to send UAVs for emergency communication to ensure the stable operation of the communication system of the Olympic Games. In the time slot t , a large number of users $\mathcal{U}^t = \{1^t, 2^t, \cdots, U^t\}$, $u^t \in \mathcal{U}^t$ need more resources than those provided by UAVs $\mathcal{V}^t = \{1^t, 2^t, \cdots, V^t\}$, $v^t \in \mathcal{V}^t$ and GBSs $\mathcal{B}^t = \{1^t, 2^t, \cdots, B^t\}$, $b^t \in \mathcal{B}^t$, UAV and GBS should be selected according to user priority ∂_{u^t} . GBS transmits data to each UAV in the network in one hop through millimeter-wave wireless communication, and each UAV transmits data to each user associated with it. In addition, each UAV can beam-form a communication beam for each user associated with it during the access time, and the beam-forming model of UAV and user adopts the sector model in the literature [29].

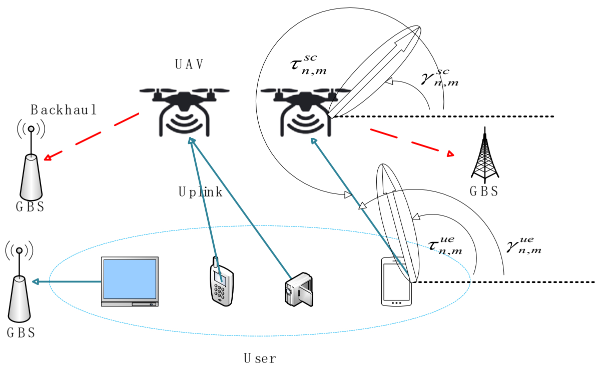

Fig. 1. An air-ground network scenario

To simplify the calculation, it is assumed that the main lobe beam widths of all UAVs in the network are equal constants. $\gamma^{sc}_{n,m}(n \in N, m \in M)$ indicates the beam visual axis angle of the n-th UAV, $\gamma^{ue}_{n,m}(n \in N, m \in M)$ denotes the beam visual axis angle of the m-th user. $\tau^{sc}_{n,m}(n \in N, m \in M)$ represents the included angle between the direction vector from UAV to user and the horizontal normal axis, and $\tau^{ue}_{n,m}(n \in N, m \in M)$ represents the included angle between the direction vector from user to UAV and the horizontal normal axis.

Table 1. Key notations

Symbol	Description
t, T	Time slot, total number of time slot.
$\mathcal{U}^t$, $\mathcal{V}^t$, $\mathcal{B}^t$	The set of users, UAV, and GBS in time slot.
u^t , v^t , b^t	The specific user $u^t \in \mathcal{U}^t$, UAV $v^t \in \mathcal{V}^t$, and GBS $b^t \in \mathcal{B}^t$
$\omega(v^t, b^t)$	Parameter to indicate the visibility of UAV v^t and GBS b^t
∂_{u^t}	Priority of user $u^t \in \mathcal{U}^t$.
$g^{sc}_{n,m}$, $g^{ue}_{n,m}$	The directional transmission gain and directional reception gain between UAV v^t and user u^t.
$SINR^t_{u,v}$	SNR of U2V channel.
$c^t_{u,v}$	Capacity of U2V channel.
$x^t_{u,v}$	Binary variable indicating whether user u^t is connected with UAV v^t.
$y^t_{v,b}$	Binary variable indicating whether UAV v^t is connected with GBS b^t .
$z^t_{u,b}$	Binary variable indicating whether user u^t is connected with UAV v^t .
$\delta^t_{u,v}$, $\delta^t_{u,b}$	Required date rate from user to UAV, Required date rate from UAV to GBS.
N_{v^t} $N^{'}_{v^t}$ N_{b^t}	The capacity of UAV v^t for users u^t , the capacity of UAV v^t for GBS b^t , and the capacity of GBS b^t for users u^t .
$P^1_{b^t}$, $P^1_{u^t}$, $P^1_{v^t}$	Preference lists of GBS b^t , users u^t , and UAV v^t .
$\mathscr{M}_1^t$, $\mathscr{M}_2^t$, $\mathscr{M}_3^t$	The matching among users, UAVS and GBS in R-TMUA algorithm, the matching between users and UAVS in the GS-based algorithm, the matching between UAVS and GBS in the RPPS-based algorithm.
$N(\mathscr{M}_1^t, n)$	Number of triples including agent n in the matching $\mathscr{M}_1^t$.
L_{b^t} , L_{v^t}	The maximum number of triples that UAV v^t takes part in $\mathscr{M}_1^t$, The maximum number of triples that GBS v^t takes part in $\mathscr{M}_1^t$.

2.2 Channel Model

In the scenario, some users are connected to the UAVs, which is then connected to the GBSs, while some other users who are close to GBSs can communicate directly, and the UAVs hovers in the air to provide access and backhaul services for users and GBSs. While the user's position and requirement in the scene change dynamically with time.

Basically, $\theta^{sc}_n (n \in N)$ represents the beam width of UAV, and $\theta^{ue}_m (m \in M)$ represents the beam width of user. In addition, $g^{sc}_{n,m} (n \in N, m \in M)$ and $g^{ue}_{n,m} (n \in N, m \in M)$ respectively represent the directional transmission gain and directional reception gain between UAV and user, the directional transmission gain of the transmitting point UAV can be expressed as:

$$g^{sc}_{n,m}(\theta^{sc}_n, \gamma^{sc}_{n,m}, \tau^{sc}_{n,m}) = \begin{cases} c, \text{if } \dfrac{\theta^{sc}_n}{2} \le |\gamma^{sc}_{n,m} - \tau^{sc}_{n,m}| \le 2\pi - \dfrac{\theta^{sc}_n}{2} \\ \dfrac{2\pi - (2\pi - \theta^{sc}_n) \times c}{\theta^{sc}_n}, \text{others.} \end{cases} \quad (1)$$

Where Sc_n is the sidelobe gain, and the beam is very thin. Similarly, the directional receiving gain Sc_n of the receiving point user u^t can be expressed as:

$$g_{n,m}^{ue}(\theta_n^{ue}, \gamma_{n,m}^{ue}, \tau_{n,m}^{ue}) = \begin{cases} c, \text{if } \dfrac{\theta_n^{ue}}{2} \le |\gamma_{n,m}^{ue} - \tau_{n,m}^{ue}| \le 2\pi - \dfrac{\theta_n^{ue}}{2} \\ \dfrac{2\pi - (2\pi - \theta_n^{ue}) \times c}{\theta_n^{ue}}, \text{others.} \end{cases} \tag{2}$$

At time slot t, the signal-to-interference noise ratio ($SINR_{u,v}^t$) of the associated UAV v^t received by the user u^t can be expressed as:

$$SINR_{u,v}^t = \frac{P_n^{sc} \times g_{n,m}^{sc} \times g_{n,m}^{ue} \times g_{n,m}^{h}}{\sum_{l \in N, l \ne n} P_l^{sc} \times g_{l,m}^{sc} \times g_{l,m}^{ue} \times g_{l,m}^{h} + N_o}. \tag{3}$$

Where P_n^{sc} represents the transmission power of UAV v^t (it is assumed that this value is a constant in the time slot t); $g_{n,m}^{h}$ represents the channel gain between UAV v^t and user u^t, $g_{n,m}^{h}$ mainly models and describes the path loss and shadowing effect on the link between UAV v^t and user u^t; N_o represents the network background noise power.

The channel capacity from the m user u^t to the n-th UAV v^t (U2V) comes from Shannon formula:

$$c_{u,v}^t = B_{u,v}^t \log_2(1 + SINR_{u,v}^t). \tag{4}$$

Where $SINR_{u,v}^t$ is the signal-to-interference noise ratio and $B_{u,v}^t$ is the attainable bandwidth from user u^t to UAV v^t. Because the application of mobile users is considered in major activities such as the Olympic Games in this work, there are almost no obstacles in this area, and the small-scale decline caused by multipath effect don't be considered.

The communication capacity of V2B channel is much larger than that of U2V channel. In this paper, the capacity limitation of V2B channel do not need to be considered.

2.3 Problem Formulation

In P0, the objective is to maximize the overall revenue generated by GBS over the entire duration T (the priority of successfully connecting users). Because users with high priority may contribute more valuable data and offer greater financial incentives to UAV and GBS, both UAV and GBS prefer to serve these users.

C1-C3 is the constraint of user and UAV access. C4-C6 indicates that the constraint of GBS and UAV access, which C6 implies that the visibility of V2B imposes a limitation on the connection of V2B. UAVs are used to share traffic in hot spots in the emergency communication scenario, some users can choose access through the remaining GBSs. To solve the above scenario problem, three novel constraints are added in this paper. C7-C8 mean that the constraint of GBS and user access. C10-C12 mean that binary variable $x_{u,v}^t$ indicate whether user u^t is connected with UAV v^t, variable $y_{v,b}^t$ indicates whether UAV v^t is connected with GBS b^t, variable $z_{u,b}^t$ indicates whether user u^t is connected with GBS b^t, and if there is, it is 1, otherwise it is 0.

It is worth noting that P0 is a NP-hard MINLP problem [26], it cannot even be guaranteed to get the solution within an acceptable period. Therefore, the R-TMUA algorithm is considered in the section III.

$$
\begin{aligned}
&P0:\max_{x,y,z}\sum_{t\in T}\sum_{u^t\in U^t}\sum_{v^t\in V^t}\sum_{b^t\in B^t}\partial_{u^t}x_{u,v}^t y_{v,b}^t z_{u,b}^t\\
&\text{s.t.}C1:\sum_{u^t\in U^t}x_{u,v}^t\le N_{v^t},\forall v^t\in\mathcal{V}^t,t\in T,\\
&\quad C2:\sum_{v^t\in V^t}x_{u,v}^t\le 1,\forall u^t\in\mathcal{U}^t,t\in T,\\
&\quad C3:\ \delta_{u,v}^t x_{u,v}^t\le c_{u,v}^t,\forall u^t\in\mathcal{U}^t,v^t\in\mathcal{V}^t,t\in T,\\
&\quad C4:\sum_{v^t\in V^t}y_{v,b}^t\le N_{b^t},\forall b^t\in\mathcal{B}^t,t\in T,\\
&\quad C5:\sum_{b^t\in B^t}y_{v,b}^t\le N_{v^t}^{'},\forall v^t\in\mathcal{V}^t,t\in T,\\
&\quad C6:\ y_{v,b}^t\le\omega(v^t,b^t),\forall v^t\in\mathcal{V}^t,b^t\in\mathcal{B}^t,t\in T,\\
&\quad C7:\sum_{u^t\in U^t}z_{u,b}^t\le N_{b^t},\forall b^t\in\mathcal{B}^t,t\in T,\\
&\quad C8:\sum_{b^t\in B^t}z_{u,b}^t\le 1,\forall u^t\in\mathcal{U}^t,t\in T,\\
&\quad C9:\ \delta_{u,b}^t z_{u,b}^t\le c_{u,b}^t,\forall u^t\in\mathcal{U}^t,b^t\in\mathcal{B}^t,t\in T,\\
&\quad C10:\ x_{u,v}^t\in\{0,1\},\forall u^t\in\mathcal{U}^t,v^t\in\mathcal{V}^t,t\in T,\\
&\quad C11:\ y_{v,b}^t\in\{0,1\},\forall v^t\in\mathcal{V}^t,b^t\in\mathcal{B}^t,t\in T,\\
&\quad C12:\ z_{u,b}^t\in\{0,1\},\forall u^t\in\mathcal{U}^t,b^t\in\mathcal{B}^t,t\in T.
\end{aligned}
\tag{5}
$$

3 Algorithm Design

P0 is solved by using the R-TMUA algorithm in each time slot in subsection 3.1. Two-levels Matching Algorithm is proposed to solve the dynamic connections in subsection 3.2. specifically, a user-UAV matching algorithm based on GS and a UAV-GBS matching algorithm based on RPPS are added.

3.1 R-TMUA Algorithm Model

In the TMUA problem, users who are directly connected to GBS don't be considered, which means that the channel link of U2B don't be considered, but only consider the users who are connected to GBS through UAV, so the users below refer to the users who are connected to GBS through UAV.

Definition 1 (Blocking triple in TMUA), a triple $(b^t,u^t,v^t)\notin\mathscr{M}_1^t$ but $(b^t,u^t,v^t)\in T$ is a blocking triple if there exists such a set:

$$
\begin{aligned}
&\{\mathscr{M}_1^t(b^t)=\varnothing\vee u^t\succ_{b^t}\mathscr{M}_1^t(b^t)\}\wedge\\
&\{\mathscr{M}_1^t(u^t)=\varnothing\vee v^t\succ_{u^t}\mathscr{M}_1^t(u^t)\}\wedge\{N(\mathscr{M}_1^t,v^t)\le L_{v^t}\},
\end{aligned}
\tag{6}
$$

indicates that GBS b^t prefers users u^t to the currently matched users $\mathscr{M}_1^t(b^t)$. Similarly, $v^t\succ_{u^t}\mathscr{M}_1^t(u^t)$ indicates that the user u^t prefers UAV v^t to the currently matched UAV $\mathscr{M}_1^t(b^t)$. $N(\mathscr{M}_1^t,v^t)\le L_{v^t}$ indicates that the total matching amount of UAV v^t should not exceed its capacity $L_{v^t}=N_{v^t}$. If there is no blocking triple in $\mathscr{M}_1^t$, the matching $\mathscr{M}_1^t$ is said to be stable.

The aim is to find the matching $\mathscr{M}_1^t=\{(b^t,u^t,v^t)\}$ so that $b^t\in P_{v^t}^1$, $v^t\in P_{u^t}^1$ and $u^t\in P_{b^t}^1$ have the largest cardinality [30].

$$\begin{aligned}
&\mathrm{P1}: \max |\mathcal{M}_1^t| \\
&\text{s.t.} C1: N(\mathcal{M}_1^t, b^t) \le L_{b^t}, \forall b^t \in \mathcal{B}^t, u^t \in \mathcal{U}^t, v^t \in \mathcal{V}^t, t \in T, \\
&C2: N(\mathcal{M}_1^t, v^t) \le L_{v^t}, \forall b^t \in \mathcal{B}^t, u^t \in \mathcal{U}^t, v^t \in \mathcal{V}^t, t \in T, \\
&C3: N(\mathcal{M}_1^t, u^t) \le L_{u^t}, \forall b^t \in \mathcal{B}^t, u^t \in \mathcal{U}^t, v^t \in \mathcal{V}^t, t \in T, \\
&C4: Bl(b^t, u^t, v^t) = 0, \forall b^t \in \mathcal{B}^t, u^t \in \mathcal{U}^t, v^t \in \mathcal{V}^t, t \in T.
\end{aligned} \quad (7)$$

Among them, C1-C3 represent the maximum number of triplets of participating GBS b^t, UAV v^t and users u^t, which are $L_{bt}(= N_{vt} \cdot N_{bt})$, L_{vt} and 1 respectively. C4 indicates that there is no blocking triplet in the final match. The R-TMUA game model for UAV-centered aerial-ground networks are shown in Fig. 2, which clearly shows the cyclic relationship among GBSs, users, and UAVs.

$$A^{+1}(\mathcal{M}_1^t, b^t) = \{u^t \mid u^t \succ b^t \mathcal{M}_1^t(b^t), u^t \in P_{b^t}^1\}, \quad (8)$$

contains the set of users that GBS b^t prefers to its existing matching $\mathcal{M}_1^t(b^t)$.

$$A^{+1}(\mathcal{M}_1^t, u^t) = \{v^t \mid v^t \succ u^t \mathcal{M}_1^t(u^t), v^t \in P_{u^t}^1\}, \quad (9)$$

indicates the set of UAVs that user u^t prefers to its current matching $\mathcal{M}_1^t(u^t)$.

$$A^{-1}(\mathcal{M}_1^t, b^t) = \{v^t \mid v^t \in \boldsymbol{V}^t, b^t \in P_{v^t}^1, N(\mathcal{M}_1^t, v^t) \le L_{v^t}\}, \quad (10)$$

denotes the set UAVs that still can accommodate GBS.

$$A^{-2}(\mathcal{M}_1^t, b^t) = \{u^t \mid u^t \in \boldsymbol{U}^t, A^{+1}(\mathcal{M}_1^t, u^t) \cap A^{-1}(\mathcal{M}_1^t, b^t) \neq 0\}, \quad (11)$$

indicates that for user u^t, there is a UAV v^t that user u^t prefers to its current matching $\mathcal{M}_1^t(u^t)$ and v^t is still able to accommodate GBS b^t.

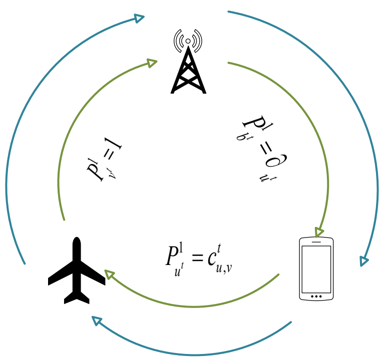

Fig. 2. model for air-ground network

Inspired by the model in the literature [31], two restrictions are added from TMUA to R-TMUA, and avid readers are encouraged to refer to [31] for a detailed understanding of the algorithm. Firstly, each GBS's preference list

$P^1_{b^t}$ for the user comes from the main preference list. This means that the lists $P^1_{b^t}$ are obtained in full or in part from the main list and all users must maintain strict order.

3.2 Two-levels Matching Algorithm

Due to the potential for slight changes in the network topology between consecutive time slots and the matching triplets, repeating R-TMUA algorithm in each time slot is redundant. When duration T is large, it prefers to use the matching results from the previous time slot.

The user-UAV matching algorithm based on GS: To mitigate the complexity arising from minor network changes between consecutive time slots, it is possible to leverage the relationship between two adjacent time slots instead of employing the R-TMUA algorithm in each time slot. Specifically, the position of the UAV and the user is relatively static, and the matching between users and UAVs can be considered as unchanged across different time periods until the user's requirement changes. GS-based matching algorithm can obtain stable matching $\mathscr{M}_2^t$ between users and UAVs.

In which, the user's preference list on UAVs is defined according to U2V channel conditions, $P^2_{u^t} = c^t_{u,v}, \forall u^t \in \mathcal{U}^t$, which is the same as that in R-TMUA algorithm. UAV's preference list for users is defined according to user's priorities, $P^2_{v^t} = \partial_{u^t}, \forall v^t \in \mathcal{V}^t$.

Definition 2 (Blocking Pair) 1) u^t is unserved or prefers v^t to its current matching $\mathscr{M}_2^t(u^t)$;

2) v^t is underutilized or prefers u^t to at least one matching in $\mathscr{M}_2^t(v^t)$. $\mathscr{M}_2^t$ is thought as stable if there exist no blocking pair for $\mathscr{M}_2^t$.

The UAV-GBS matching algorithm based on random path to pair stable (RPPS): After obtaining the matching result between user and UAV, the matching between UAV and GBS presents a many-to-many matching problem that needs to be addressed. Inspired by [15] and [16], a matching algorithm based on random path to pair stable is considered.

Definition 3 (Substitutable Preference): Let R_b be the set of potential GBS (partners) for UAV v^t, $R_b \subseteq \mathsf{R}_b$. The preference list of UAV v^t is substitutable if for any GBS b^t, $b'^t \in F_{v^t}(R_b), b^t \in F_{v^t}(R_b \setminus \{b'^t\})$. $F_{v^t}(R_b)$ denotes the subset of R_b that UAV v^t wishes to match to.

It essentially means that for UAV v^t, a GBS chosen from a larger potential GBS set is always chosen from a smaller potential GBS set.

Definition 4 (Responsive Preference): For each GBS b^t with maximum size N_{bt}, its preference is responsive with quota N_{bt} if: 1) for all $v^t \in \mathsf{J}_v$, and $J_v \subseteq \mathsf{J}_v \setminus v^t$ with $|J_v| < N_{b^t}$, $v^t \cup \mathrm{J}_v \succeq_{b^t} J_v \Leftrightarrow v^t \succ_{b^t} \varnothing$;

2) for all v^t, $v'^t \in \mathsf{J}_v$, and all $J_v \subseteq \mathsf{J}_v \setminus \{v^t, v'^t\}$, with $|J_v| < N_{b^t}$, $v^t \cup J_v \succeq_{b^t} v'^t \cup J_v \Leftrightarrow v^t \succ_{b^t} v'^t$;

3) for all $J_v \subseteq \mathsf{J}_v$ with $|J_v| > N_{b^t}$, $\varnothing \succ_{b^t} J_v$. J_v is the set of UAVs (partners) for GBS b^t, $J_v \subseteq \mathcal{J}_v$.

In other words, GBS b^t prefers adding an acceptable UAV unless reaching the quota (N_{bt}) and it prefers replacing a UAV with a better one when the quota (N_{bt}) is exhausted. Besides, GBS b^t prefers to being unmatched if any subset J_v exceeds the quota (N_{bt}).

Definition 5 (Pairwise-Stable): A matching $\mathscr{M}_3^t$ is pairwise-stable if: 1) there is no blocking individuals v^t or b^t that $\mathscr{M}_3^t(v^t) \neq F_{v^t}(\mathscr{M}_3^t(v^t))$ or $\mathscr{M}_3^t(b^t) \neq F_{b^t}(\mathscr{M}_3^t(b^t))$; 2) there exists no blocking pair (v^t, b^t) with $v^t \notin \mathscr{M}_3^t(b^t)$ and $b^t \notin \mathscr{M}_3^t(v^t)$ such that $\mathsf{R}_b \in F_{v^t}(\mu(v^t, \mathscr{M}_3^t) \cup \{b^t\})$ and $\mathsf{J}_v \in F_{b^t}(\mu(b^t, \mathscr{M}_3^t) \cup \{v^t\})$, then $\mathsf{R}_b \succ_{v^t} \mu(v^t, \mathscr{M}_3^t)$ and $\mathsf{J}_v \succ_{b^t} \mu(b^t, \mathscr{M}_3^t)$. $\mu(i, \mathscr{M}_3^t)$ is the set of $j \in \mathcal{V}^t \cup \mathcal{B}^t$ such that $i \in \mathscr{M}_3^t(j)$ and $j \in \mathscr{M}_3^t(i)$. It means that a matching $\mathscr{M}_3^t$ for UAVs and GBSs is pairwise-stable if $\mathscr{M}_3^t$ is neither blocked individually nor blocked in pairs.

The UAV preference list on the GBS, which is $P^3_{v^t} = 1, \forall v^t \in \mathcal{V}^t$, continues to be used to meet the alternative preference. The preference list of GBS on UAV is related to the matching result $\mathscr{M}_2^t$ of users and UAVs in GS algorithm, which is $P_{b^t}^3 = |\mathscr{M}_2^t(b^t)|, \forall b^t \in \mathcal{B}^t$, where $|\mathscr{M}_2^t(v^t)|$ is the total number of matching users of UAV v^t. Specially, $P_{b^t}^3$ reflects the coupling between user-UAV matching algorithm based on GS and a UAV-GBS matching algorithm based on RPPS.

The input of the algorithm is the user $\mathcal{U}^t$, the UAV $\mathcal{V}^t$, and the GBS $\mathcal{B}^t$. The algorithm is initialized to the preference list of user $P_{u^t}^1$, UAV $P_{v^t}^1$, and GBS $P_{b^t}^1$. At time slot $t = 1$, the R-TMUA matching algorithm is performed. If the user's requirements change, the GS-based matching algorithm is executed. Select the best UAV $v^t \in P_{u^t}^2$, then select the user u'^t with the worst match, exchange the user u'^t with the current match u^t, and form a new pair (u^t, v^t) to add the final matching result $\mathscr{M}_2^t$, as shown in lines 8-18. If the user's requirement doesn't change, the RPPs matching algorithm is executed. Then, the algorithm checks for any UAV-pointed blocking pairs $\{(v^t, b^t)\}$ in $\overline{I}$ and let UAV v^t match with its most preferred GBS in $\{(v^t, b^t)\}$. This process occurs in lines 22-26 of the algorithm. Next, if there are any GBS-pointed blocking pairs $\{(v^t, b^t)\}$ in $\overline{I}$ and let GBS b^t match with its most preferred UAV in $\{(v^t, b^t)\}$. This step is outlined in lines 29-34 of the algorithm. Finally, the pairwise matching results is updated as $\mathscr{M}_3^t = M_i$ in time slot t.

Algorithm 1. GBS-oriented two-levels matching algorithm

Input: $\mathcal{B}^t$, $\mathcal{U}^t$, $\mathcal{V}^t$.
Output: $\mathscr{M}_1^t$, $\mathscr{M}_2^t$, $\mathscr{M}_3^t$.
Initialization: Construct the preference lists $P_{b^t}^1$, $P_{u^t}^1$, $P_{v^t}^1$ .set $\mathscr{M}_1^t = \varnothing$.
1.for $1 \le t \le T$ do
2. if $t = 1$ then
3. Get the matching result $\mathscr{M}_1^t$ among users, UAVs, and GBSs by R-TMUA algorithm.
4. else
5. if user's requirement doesn't change in t compared with the demand in $t-1$ then
6. Go to step 21
7. else
8. Obtain the matching result $\mathscr{M}_2^t$ between users and UAVs by GS-Based Matching Algorithm.
9. Construct the preference lists $P_{u^t}^2$ and $P_{v^t}^2$, Set $\mathscr{M}_2^t = \varnothing$.
10. for each unmatched user u^t do
11. Choose the best UAV $v^t \in P_{u^t}^2$ as $\mathscr{M}_2^t(u^t)$
12. if $|\mathscr{M}_2^t(v^t)| == N_{v^t}$ then
13. Choose the worst matched user u'^t in $\mathscr{M}_2^t(v^t)$.
14. if $u^t \succ_{v^t} u'^t$ then
15. Swap u^t and u'^t in $\mathscr{M}_2^t(v^t)$
16. end if
17. end if
18. Add pair (u^t, v^t) in $\mathscr{M}_2^t$.
19. end for.
20. end if
21. Using RPPS Matching Algorithm to get the pairwise-stable matching $\mathscr{M}_3^t$ between UAVs and GBSs.
22. Updated preference lists $P_{v^t}^3$ and $P_{b^t}^3$. Let $M_i = \mathscr{M}_3^{t-1} \setminus M_{b^{t-1}}$, and $\overline{I} = \varnothing$.
23. while there are any blocking pairs $\{(v^t, b^t)\}$ for UAV v^t in $\overline{I}$ do
24. if the quota of v^t is exhausted then
25. $M_i = M_i \setminus \mathrm{Worst}\{(v^t, M_i(v^t))\}$
26. $M_i = M_i \cup \mathrm{Best}\{(v^t, b^t)\}$

    end if
  end while
  while there are any blocking pairs $\{(v^t, b^t)\}$ for GBS b^t in $\overline{I}$ do
    if the quota of b^t is exhausted then
      $M_i = M_i \setminus \mathrm{Worst}\{(b^t, M_i(b^t))\}$
      $M_i = M_i \cup \mathrm{Best}\{(v^t, b^t)\}$
    end if
  end while
  $\mathscr{M}_3^t = M_i$
end if
end for

4 Simulation and Analysis

A series of simulations is conducted in the air-ground network scenario composed of users, UAVs, and GBSs in this section. MATLAB is used to realize the proposed algorithm and output the corresponding results. To verify the performance of the optimization algorithm proposed in this paper, the optimization algorithm with the random matching algorithm is compared and analyzed.

4.1 Parameter Setting

In the simulation, 66 UAVs and 4 available GBSs are randomly distributed in the setting scene, and the number of users in each time slot is [20,220]. All users are in the coverage of UAV, and the transmission power of UAV and each user is constant. The capacity set by UAV for users and GBSs is 40 and 2 respectively, and the capacity set by GBSs for UAV is 2. Other main parameters used in the algorithm simulation are given in the Table 2.

Table 2. Primary simulation parameters

Parameter	Value
$\mathcal{U}^t$	[20,220]
$\mathcal{V}^t$	66
$\mathcal{B}^t$	4
t	200s
$c_{u,v}^t$	2M Hz
UAV radius	500 m
N_{v^t}	40
Carrier frequency/available bandwidth	60G Hz/2G Hz
Noise power spectral density	-23 $\mathrm{dBm \cdot Hz^{-1}}$
Shadow standard deviation	12dB
N_{b^t}	2
N'_{v^t}	2

4.2 Algorithm Astringency Analysis

Fig. 3 studies the iteration times of R-TMUA, GS+RPPS and random matching algorithm in different time slots. The iteration number of random matching is the lowest and compared with the iteration number of R-TMSC algorithm, the iteration number of GS+RPPS is even less. Fig. 3 shows that R-TMUA algorithm and GS+RPPS algorithm can be iterated in a limited number of times. Especially, because the changes of UAV and GBS in adjacent time slots are very small in practice, GS+RPPS algorithm can obtain the paired stable matching results of the current time slot only by slightly modifying the paired stable matching results of the previous time slot, which is the fundamental reason for the low time complexity of GS+RPPS.

The change rate in Fig. 4 is the slope, in which the ratio of the change of households to the change of UAV. From the figure, it can show that both the R-TMUA algorithm and the GS+RPPS algorithm fluctuate within the range of 0.4, indicating that the R-TMUA algorithm and the GS+RPPS algorithm have good convergence, but the convergence random matching algorithm is the best without considering the revenue and time.

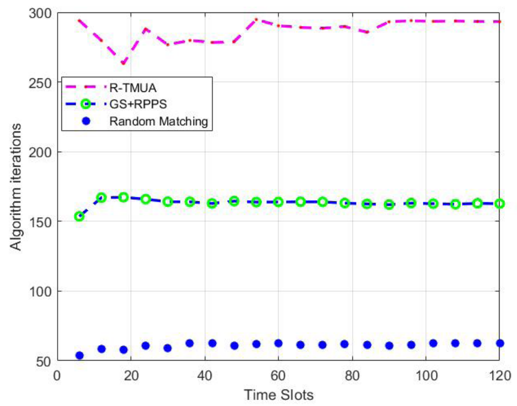

Fig. 3. Algorithm iterations v.s. time slots

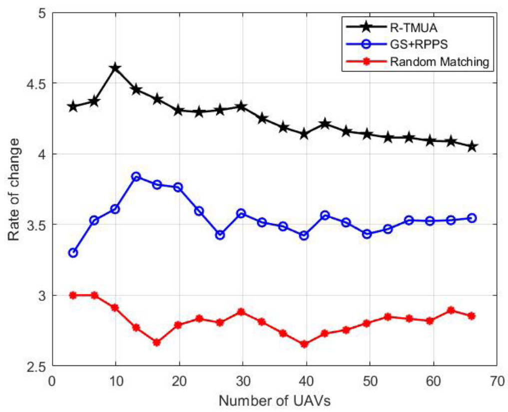

Fig. 4. Rate of change v.s. number of UAVs

4.3 Algorithm Efficiency Analysis

From the observation of Fig. 5, it is evident that the R-TMUA algorithm exhibits relatively lower time efficiency, displaying a logarithmic growth relationship with the number of users. However, the time overhead of other methods remains within an acceptable range. Both R-TMUA algorithm and GS+RPPS algorithm demonsrate higher time efficiency, and GS+RPPS algorithm is better than R-TMUA algorithm when there are many users. Due to the increase of the cumulative number of successfully matched users, all algorithms show a steady growth trend. The performance of the GS+RPPS algorithm closely approximates that of the R-TMUA algorithm. Although the random matching algorithm in Fig. 6 is not weaker than the algorithm proposed, and the random matching has a lower number of iterations.At the same time, Fig. 6 indicate the total number of users who have served is close to the optimal solution in both R-TMUA and GS+RPPS algorithms, and R-TMUA performs better than GS+RPPS.

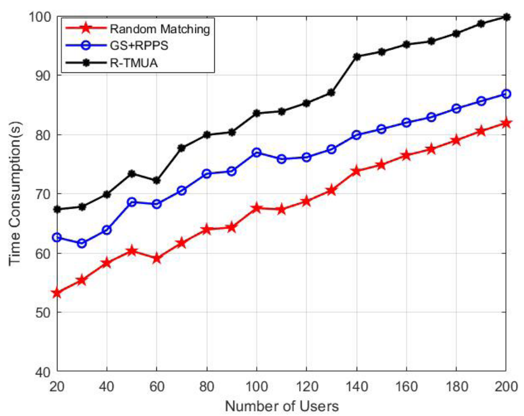

Fig. 5. Time consumption v.s. number of users

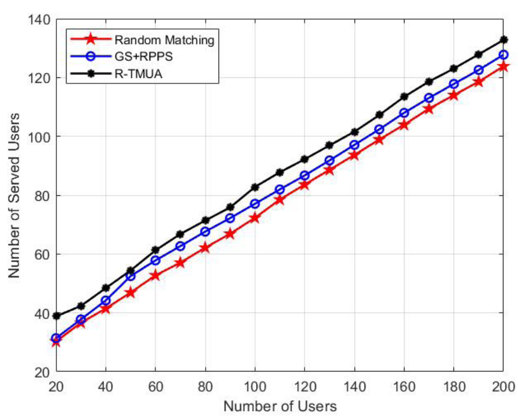

Fig. 6. Number of served users v.s. number of users

4.4 Algorithm Revenue Analysis

In Fig. 7, Fig. 8 and Fig. 9, the trend of total GBS revenue with an increasing number of users exhibits a corresponding variation, UAVs and time slots is also studied. Fig. 7 investigates the correlation between the revenue of GBSs and the number of matched users. Fig. 7 shows that GBS revenue of the random matching algorithm is far from that of the R-TMUA algorithm and GS+RPPS algorithm, so the random matching algorithm cannot be selected.

In Fig. 8, the relationship between the revenue of GBSs and the number of UAVs is studied. As the cumulative number of UAVs successfully matched increases, all algorithms show a steady growth trend. Once the number of UAVs reaches 66, the benefits derived from all algorithms do not show any further increase, because the GBSs supports 66 UAVs at most, and all users have been covered, and the matching results are basically stable, so it is useless to increase the number of UAVs.

In Fig. 9, the relationship between time slots and total GBSs revenue is studied, and the GBS revenue obtained by some users moving in random directions at a speed of 1.5 *m/*s. Among them, GBS benefits corresponding to all algorithms increases steadily, but the GS+RPPS algorithm exhibits inferior performance compared to the R-TMUA algorithm, and the random matching algorithm has the worst effect.

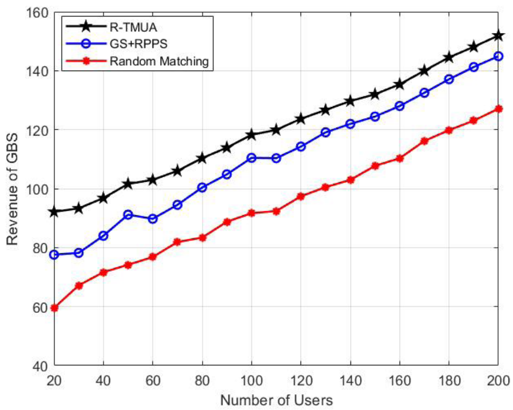

Fig. 7. Revenue of GBS v.s. number of users

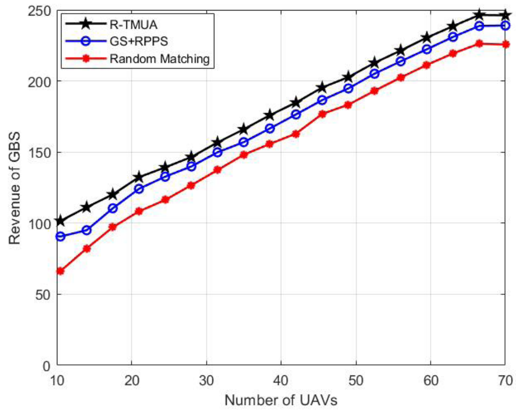

Fig. 8. Revenue of GBS v.s. number of UAVs

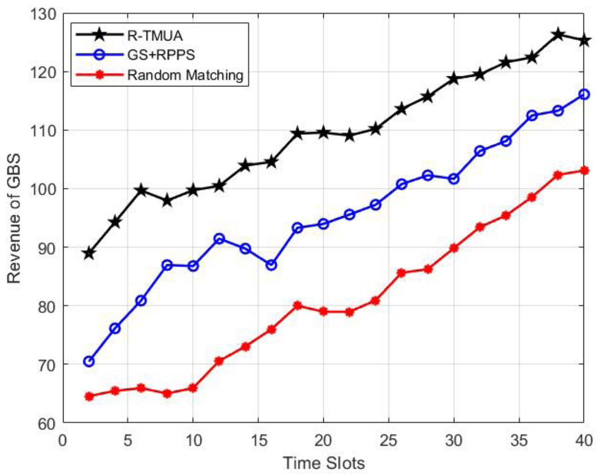

Fig. 9. Revenue of GBS v.s. time slots

According to the simulation results, as the number of slots increases, the time complexity of the GS+RPPS algorithm is observed to be lower than that of the R-TMUA algorithm, but R-TMUA has more iterations, and its performance is not excellent enough. The matching result of R-TMSC is better, but the time complexity is higher. Therefore, two algorithms are flexibly selected according to specific scenarios and requirements in practical application.

5 Conclusion and Future Work

A stable user association based on millimeter wave in the integrated air-ground network is proposed. Including users, UAVs, and GBSs, a Two-levels Matching algorithm to solve the proposed problem. In addition, to solve the dynamic connection between UAV and users causes the algorithm to run repeatedly, the GS+RPPS matching algorithm is further designed to get a new stable match. Finally, simulation results provide evidence of the convergence and efficiency of the proposed algorithm. This paper only studies the optimization method of user association in the integration of the world network and will further study the joint optimization method of user association and resource allocation in the 6th generation (6G) network.

6 Acknowledgement

This work was supported in part by National Natural Science Foundation of China (Grant No. 62261050), Natural Science Foundations of Gansu (Grant No. 21JR7RA119, 21JR7RA208), Industrial Support Foundations of Gansu (Grant No. 2021CYZC-06, 2022CYZC-12), Science and Technology Foundation of Lanzhou (Grant No. 2017-4-101), Young Teachers' Scientific Research Ability Promotion Foundation of Northwest Normal University (Grant No. NWNU-LKQN2021-04), Open Project of Gansu Provincial Research Center for Conservation of Dunhuang Cultural Heritage (Grant No. GDW2021ZD04) and Innovation Foundation of Gansu Universities (Grant No. 2022A-015).

References

[1] R. Salama, F. Al-Turjman, D. Bordoloi, S.-P. Yadav, Wireless Sensor Networks and Green Networking for 6G communication-An Overview, in: Proc. 2023 International Conference on Computational Intelligence, Communication Technology and Networking, 2023.

[2] S.-M. Periannasamy, C. Thangavel, S. Latha, G.V. Reddy, S. Ramani, P.V. Phad, S.R. Chandline, S. Gopalakrishnan, Analysis of Artificial Intelligence Enabled Intelligent Sixth Generation (6G) Wireless Communication Networks, in: Proc. 2022 IEEE International Conference on Data Science and Information System, 2022.

[3] N. Cheng, F. Lyu, W. Quan, C.-H. Zhou, H.-L. He, W.-S. Shi, and X.-M. Shen, Space/aerial-assisted computing offloading for IoT applications: A learning-based approach, IEEE Journal on Selected Areas in communications 37(5) (2019) 1117-1129 .

[4] K.-G. Panda, S. Das, D. Sen, W. Arif. Design and deployment of UAV-aided post-disaster emergency network, IEEE Access 7(2019) 102985-102999.

[5] X. Li, J.-W Tan, A.-F Liu, P. Vijayakumar, N. Kumar, M. Alazab, A novel UAV-enable data collection scheme for intelligent transportation system through UAV speed control, IEEE Transactions on Intelligent Transportation Systems 22(4) (2021) 2100-2110.

[6] Q. Wu, J. Sheng, C. Wu, J. Zhang, Y. Wang, Research on UAV networking technology for high-speed railway emergency eommunication, International Wireless Communications and Mobile Computing (2021) 1557-1562.

[7] M.-H. Eiza, A. Raschellà, A Hybrid SDN-based architecture for secure and QoS aware routing in space-air-ground integrated networks (SAGINs), in: Proc. 2023 IEEE Wireless Communications and Networking Conference, 2023.

[8] H.-X. Cui, J. Zhang, Y.-H. Geng, Z.-Y. Xiao, T. Sun, N. Zhang, J.-J. Liu, Q.-H. Wu, X.-B. Cao, Space-air-ground integrated network (SAGIN) for 6G: Requirements, architecture and challenges, China Communications 19(2)(2022) 90-108.

[9] F.-X. Tang, C. Wen, L.-F. Luo, M. Zhao, N. Kato, Blockchain-based trusted traffic offloading in space-air-ground integrated networks (sagin): A federated reinforcement learning approach, IEEE Journal on Selected Areas in Communications 40(12)(2022) 3501-3516.

[10] B. Yang, S.-Y. Liu, T. Xu, C.-Y. Li, Y.-D. Zhu, Z.-P. Li, Z.-F Zhao, AI-Oriented Two-Phase Multifactor Authentication

in SAGINs: Prospects and Challenges, IEEE Consumer Electronics Magazine (2023).
[11] X.-P. Wang, L.-T. Yang, D.-D. Meng, M.-X. Dong, K. Ota, H.-F. Wang, Multi-UAV cooperative localization for marine targets based on weighted subspace fitting in SAGIN environment, IEEE Internet of Things Journal 9(8)(2022) 5708-5718.
[12] M.-D. Zakaria, D. Grace, P.-D. Mitchell, T.-M. Shami, N. Morozs, Exploiting user-centric joint transmission—Coordinated multipoint with a high-altitude platform system architecture, IEEE Access 7(2019) 38957–38972.
[13] T. Hong, W.-T. Zhao, R.-K. Liu, M. Kadoch, Space-air-ground IoT network and related key technologies, IEEE Transactions on Wireless Communications 27(2)(2020) 96-104.
[14] S. Yan, L. Qi, M. Peng, M.-G. Peng, User access mode selection in satellite-aerial based emergency communication networks, in: Proc. 2018 IEEE International Conference on Communications Workshops, 2018.
[15] Z.-C. Yuan, K.-S Jiang, W.-J Jia, R.-W. Liu, Z.-J. Wang, X.-Y. Mao, Interference coordination and throughput maximization in an unmanned aerial vehicle-assisted cellular: User association and three-dimensional trajectory optimization, IET Communications 15(10)(2021) 1273-1286.
[16] J.-X. Chen, Q.-H. Wu, Y.-H. Xu, N. Qi, T. Fang, D.-X. Liu, Spectrum allocation for task-driven UAV communication networks exploiting game theory, IEEE Wireless Communications 28(4)(2021) 2384-2397.
[17] X. Sun, N. Ansari, R. Fierro, Jointly Optimized 3D drone mounted base station deployment and user association in drone assisted mobile access networks, IEEE Transactions on Vehicular Technology 69(2)(2020) 2195-2203.
[18] C.-Y. Pan, C.-C. Yin, N.-C. Beaulieu, J. Yu, 3D UAV placement and user association in software-defined cellular networks, Wireless Networks 25(7)(2019) 3883-3897.
[19] Y.-H. Ruan, Y.-Z. Li, C.-X. Wang, R. Zhang, Energy efficient adaptive transmissions in integrated satellite-terrestrial networks with SER constraints, IEEE Transactions on Wireless Communications 17(1)(2017) 210-222.
[20] H.-Q. Zhang, Y. Xiao, S.-R. Bu, D. Niyato, F.-R. Yu, Z. Han, Computing resource allocation in three-tier IoT fog networks: A joint optimization approach combining Stackelberg game and matching, IEEE Internet of Things Journal 4(5) (2017) 1204-1215.
[21] Z.-Y. Miao, Y. Wang, Z. Han, A supplier-firm-buyer framework for computation and content resource assignment in wireless virtual networks, IEEE Transactions on Wireless Communications 18(8)(2019) 4116–4128.
[22] S.-S. Metwaly, A.-M. El-Haleem, O.-M. El-Ghandour, No-Regret Matching Game Algorithm for NOMA Based UAV-Assisted NB-IoT Systems, Ingénierie des Systèmes d'Information 26(1)(2021) 79-85.
[23] X. Huang, H.-R. Liu, X.-H. Liu, X.-Q. Wang, Y.-F. Zhao, Research on Beam Allocation of Millimeter Wave Massive MIMO based on Matching Game, Journal of Physics: Conference Series 2447(2023) 012005.
[24] D. Das, R.-K. Khadanga, D.-K. Rout, A matching game framework for users clustering and resource allocation with wireless power transfer in a cr-noma network, International Journal of Communication Systems 36(2)(2022) e5376.
[25] D.-F. Manlove, Algorithmics of Matching Under Preferences, vol. 2, World Scientific, Singapore, 2013.
[26] V. -V. Vazirani, Approximation Algorithms, vol. 1, Springer, 2001.
[27] Z. Zhang, X.-Y. Kou, I. Palomares, W.-Y. Yu, J.-L. Gao, Stable two-sided matching decision marking with incomplete fuzzy preference relations: A disappointment theory based approach, Applied Soft Computing 84(2019) 105730.
[28] Y.-M. Miao, R. Du, J. Li, J.-C. Westland, A two-sided matching model in the context of B2B export cross-border e-commerce, Electronic Commerce Research 19(2019) 841-861.
[29] H.-C. Zhuang, J. Chen, D.-O. Wu, Joint access and backhaul resource management for ultra-dense networks, in: Proc. 2017 IEEE International Conference on Communications, 2017.
[30] N. Raveendran, Y.-N. Gu, C.-X. Jiang, N.-H. Tran, M. Pan, L.-Y. Song, Z. Han, Cyclic three-sided matching game inspired wireless network virtualization, IEEE Transactions on Mobile Computing 20(2)(2021) 416-428.
[31] W.-Y. Huang, T. Song, J.-P. An, QA2: QoS-guaranteed access assistance for space–air–ground internet of vehicle networks, IEEE Internet of Things Journal 9(8)(2022) 5684-5695.