UAV-Assisted 6G Wireless Networks: An Adaptive Auction Over the Sky

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Abstract

In this paper, we investigate the UAV- assisted wireless communication system. We formulate the wireless resource (i.e., bandwidth) allocation problem based on the proposed system model as the resource competition game with the aim of maximizing the total network utility. Then, we apply the generalized Kelly mechanism (GKM) framework in order the address the proposed problem where the UAV serves as the seller and the mobile users as the buyers. In the proposed framework, the buyers bid to get the required resource from the seller, and then the seller collects all bids submitted from the buyers and decide the resource allocation scheme. Simulation results show that our proposed algorithm outperforms other schemes.

1. Introduction

Nowadays, with the explosive growth of the active device connections (i.e., smartphones, IoTs, tablets, etc.), numerous computation-intensive applications come up in our daily life. However, these devices have limited battery lifetime and computation capacity. Therefore, devices offload their computation tasks to the cloud servers or mobile edge computing (MEC) servers located at the edge of the servers; however, it can create not only a burden on the current wireless networks but also to install more network infrastructures (i.e., wireless base stations, cell towers, etc.). Nonetheless, the cost of building infrastructure (i.e., capital expenditure) and the cost of service are high. Recently, many researchers focus on deploying the unmanned aerial vehicles (UAVs) for the wireless communication networks because it is flexible to deploy, and the deployment cost is lower than the normal wireless infrastructures [1] [2] [3]. However, there are still challenges to address before deploying widely. Among them, one of the critical issues is the efficient resource allocation. Therefore, in this work, we propose the efficient resource allocation framework in the UAV-assisted wireless network by using the generalized Kelly mechanism (GKM) [4].

2. System Model

As illustrated in Fig.1, we consider a UAV-assisted wireless network in which there is a UAV that is hovering over the a set of ground devices denoted by $\mathcal{U} = \{1, 2, \dots, U\}$ and provides a communication services to ground devices. Let (x_0, y_0, z_0) and (x_u, y_u, z_u) be the locations of UAV and device u, respectively. It is noted that UAV is assumed to be hovering at the fixed altitude. Considering that the ground devices can access to UAVs through line-of- sight links and free-space path loss model is adopted, the channel gain between device u and UAV is denoted as,

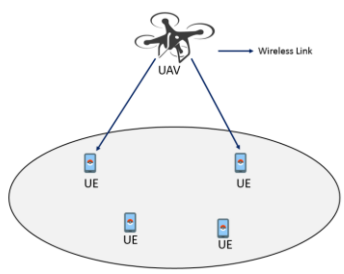

Fig. 1. System Model.

$$h_{u,0} = \frac{h_0}{\|d_{u,0}\|_2^2}, \quad (1)$$

where $d_{u,0} = (x_0 - x_u)^2 + (y_0 - y_u)^2 + (z_0 - z_u)^2$, is the distance between device u and UAV and h_0 is the channel gain at reference distance of 1 m. The achievable data rate between the device u UAV is described as,

$$R_{u,0} = d_u \log_2(1 + \frac{P_{u,0} h_{u,0}}{N_0}), \quad (2)$$

where d_u is the bandwidth allocated to the device u, $P_{u,0}$ is the transmit power of the UAV and N_0 is the noise power spectral. It is assumed that UAV transmits with uniform power to all users.

3. Problem Formulation

Based on the QoS requirement, each mobile device Establishes the demand of bandwidth. Let us denote the valuation function $v_u(d_u(b)) = \log\left(d_{u,0}\log_2(1+\frac{P_{u,0}h_{u,0}}{N_0}\right)$ as the satisfaction of the device. Then, each

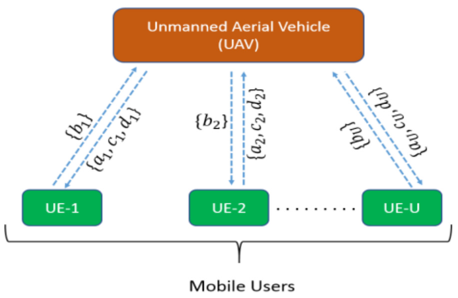

Fig. 2. GKM model.

device report the bidding value to the UAV in order to get the required bandwidth resource. According to the reported bidding values of devices, UAV allocates its wireless bandwidth to each device. It means that the device with the higher bidding value will receive more bandwidth from the UAV. Thus, cooperation between the UAV and the ground mobile devices can be configured as a GKM structure where the goal of the UAV is to optimize the aggregated valuation of all the ground devices. Therefore, we can write bandwidth allocation problem as follows:

$$\max_{d_u} \quad \sum_{u=1}^{U} v_u(d_u(b))$$

subject to:

$$\boldsymbol{d_u(b)} \cap d_t(\boldsymbol{b}) = \emptyset,\ \boldsymbol{for\ \ u \neq t}, \quad \boldsymbol{and\ \ u,t \in \mathcal{U}}, \quad (4)$$

$$\textstyle\sum_{u=1}^{U} d_u(\boldsymbol{b})\, D, \quad (5)$$

$$d_u(\boldsymbol{b}) \ \geq\ \boldsymbol{0},\ \forall \boldsymbol{u} \in \boldsymbol{\mathcal{U}}, \quad (6)$$

Where constraint (1) ensures an isolation amongst devices. As the system bandwidth of UAV is limited, constraint (2) ensures that all devices' allocated bandwidth does not surpass the UAV's total network bandwidth.

Then, the bidding value of each device u can be calculated as follows:

$$b_u \ = \ \frac{1}{a_u} d_u(b) v_u'(d_u(b))(1-\delta_u), \quad \forall u \in \mathcal{U}. \quad (7)$$

After receiving all bidding values from the device, the UAV allocated the bandwidth resource to each device. Then, the bandwidth resource allocated to the device u can be calculated as follow:

$$d_u(b) \ = \ \frac{b_u}{\sum_{u=1}^{U} b_u} D, \qquad \forall u \in \mathcal{U}, \qquad (8)$$

Then, depending on the bidding value b_u, the UAV imposes the cost function $c_u(b)$ of the device as $a_u b_u$ where a_u is the penalty value of the device u. Finally, the payoff (i.e., utility) of the device u can be expressed as:

$$y_u(b) \ = \ v_u(d_u(b)) \ - \ a_u b_u\ , \quad \forall u \in \mathcal{U}, \quad (9)$$

Moreover, let consider $\boldsymbol{a} = \{a_1, a_2, \ldots, a_U\}$ as the vector of penalty values of all devices and the penalty value of the device u as follows:

$$a_u \ = \ \frac{1}{\beta} v_u'(d_u)(1-\frac{d_u}{D}), \qquad \forall u \in \mathcal{U}\ , \quad (10)$$

where β is the virtual price of the resource. Here, each ground device should choose its best strategy, i.e., bidding value, to optimize its own payoff/utility. Hence, the utility of the device u when choosing its strategy b_u is as follows:

$$y_u(b_u; \boldsymbol{b}_{-u}, \boldsymbol{a}) \ = \ v_u(d_u(b)) - a_u b_u,\ \forall u \in \mathcal{U}, \quad (11)$$

where $\boldsymbol{b}_{-u} = [b_1, \ldots b_{u-1}, b_{u+1}, \ldots, b_U]$ is the strategy profiles of all other devices except u. The strategy profile b_u^* is the best strategy of the device u and a Nash equilibrium exists when the following condition is met for all ground devices:

$$y_u(b_u^*; \boldsymbol{b}_{-u}^*, a) \geq y_u(b_u; \boldsymbol{b}_{-u}^*, a), \qquad \forall b_u \geq 0. \qquad (12)$$

4. Simulation Results

In this section, we will demonstrate the numerical results of our proposed model. In this paper, we consider the UAV is hovering over the $(70\times\ 70)\ m^2$ coverage area and the ground devices, U =30 are randomly distributed around the UAV's coverage area. The noise power density is −174dBm/Hz and the total transmit power of the UAV is 1 W.

In Fig. 3, we show the comparisons of achieved social welfare with our proposed solution and other algorithms. From Fig. 8, it is clear that our proposed algorithm has higher social welfare than the traditional Kelly Mechanism and Equal Sharing. Moreover, achieved social welfare under proposed solution is approximately close to the maximum/optimal social welfare.

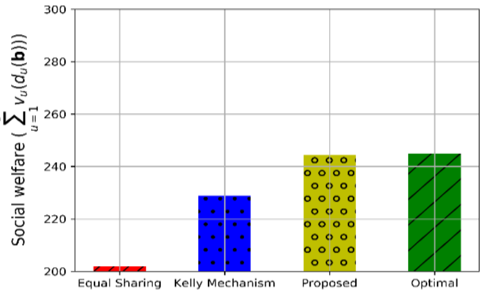

Fig. 3. Comparisons of social welfare with proposed solution with other algorithms.

Finally, the fairness index among ground devices is presented in Fig. 4. For the fairness, we use the Jain's fairness index [5],

$$f(v_1, v_2, \ldots, v_U) = \frac{(\sum_{u=1}^{U} v_u)^2}{U \sum_{u=1}^{U} v_u^2} \qquad (13)$$

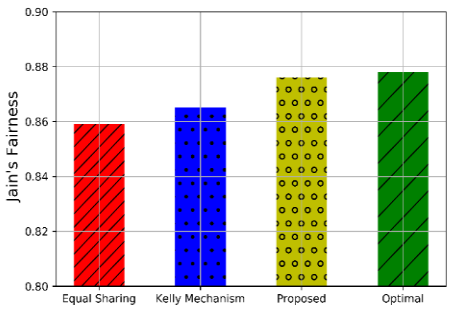

Fig. 4. Fairness among ground devices.

where Jains fairness index lies between [0,1] (e.g., the fairness index 0.9 means that the resource allocation among ground devices is 90 % fair). we can observe that the fairness index of our proposed GKM algorithm is 0.876, traditional Kelly Mechanism is 0.866 and equal sharing is 0.85. Moreover, the fairness index of proposed solution is close to fairness index of the optimal solution.

5. Conclusion

In this paper, we have formulated optimal resource allocation problem in the UAV-assisted wireless network. Then, we apply the GKM mechanism in order to solve the proposed problem. Finally, we show that the social welfare achieved under our proposed algorithm is higher than others under traditional Kelly mechanism and the equal sharing.

In future, we will consider the UAV's trajectory optimization.

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