User-Association for Sum Rate Maximization in Air-Ground Integrated Network

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Abstract

In the next generation network, the need of enormous conventional small cell base stations becomes higher to satisfy the unprecedented growth of users' demand. However, deploying them may incur CAPEX and OPEX to create better future network. In this paper, unmanned aerial vehicle-assisted wireless network is proposed in which user association problem is addressed to maximize the sum rate of the network. Particularly, each user will connect to either aerial base station or terrestrial base station in the downlink so that its data rate can be maximized. We formulate our user association problem as an assignment problem and apply mixed integer programming to solve it.

1. Introduction

The use of UAVs (Unmanned Aerial Vehicles) as aerial base stations can provide wireless connection on the fly and establish line-of-sight links to the ground users [1]. When compared to conventional terrestrial network, flying base stations deployed in three-dimensional space can provide wider coverage, on-demand connectivity and reliable connection to the users. They can also help the network recovery in the case of ground base station failure due to the natural disaster. Moreover, they can be integrated to the existing terrestrial network as the assistance for extending the coverage and enhancing the network capacity. There are many challenges in UAV communication network, such as air-to-ground channel modeling, hover time optimization, power allocation, energy-efficient deployment and so on.

The main challenge to be tackled in such kind of UAV-assisted network is the association of users to aerial and ground base stations by fulfilling the data rate requirement of users. In this paper, we address the problem of user association to aerial and ground base stations so that the sum rate of the system is maximized. We assume that there is a central controller in the system to collect the information about users and base stations. All base stations adopt FDMA (Frequency Division Multiple Access) technique to serve their associated users. We consider rotary-wing UAVs in our system because they can hover as well as fly above the area of interest to serve ground users.

The rest of the paper is as follows. In Section 2, we present the system model and problem formulation is described in Section 3. Simulation results are shown in Section 4 and conclusion of the paper is presented in Section 5.

2. System Model

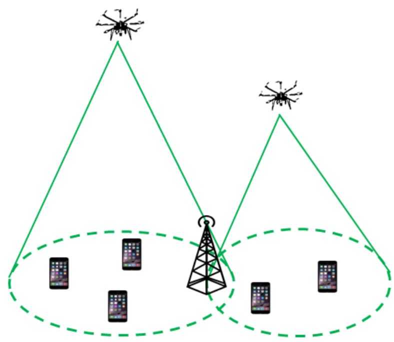

Fig.1. System Model.

For our system model as shown in Fig.1, we consider a UAV-assisted wireless network in a certain geographical area where there are a set $\mathcal{U} = \{1,2,\dots,U\}$ of ground users (GUEs), a set $\mathcal{K} = \{0,1,2,\dots,K\}$ of base stations (aerial and terrestrial base stations). Index 0 in $\mathcal{K}$ denotes that only one terrestrial base station is considered in the system. Here, the role of UAVs is to assist the existing terrestrial network as aerial small cell base stations that provide wireless access to the ground users and extend the coverage. The ground users will connect to either aerial base station or ground base station so that the sum rate of the system is maximized. We assume that all aerial base stations (ABSs) and terrestrial base station (GBS) adopt FDMA technique while serving their associated users [2].

2.1 Air-Ground Communication Model

Taking into account scattering, multi-path components due to reflection, foliage, and so on, we consider the probabilistic path loss model for air to ground channel. The path loss between ABS k and GUE u is calculated as [3],

$$\beta_{k,u} = \begin{cases} (\frac{4\pi f d_0}{c})^2 (\frac{d_{k,u}}{d_0})^2 \eta_{LoS} \\ (\frac{4\pi f d_0}{c})^2 (\frac{d_{k,u}}{d_0})^2 \eta_{NLoS} \end{cases}, \quad (1)$$

where f is the carrier frequency, c is the speed of light, η_{LoS} and η_{NLoS} are the attenuation factors for line-of-sight and non-line-of-sight link respectively and d_0 is the free-space reference distance ($d_0 = 1\ m$). $d_{k,u}$ is the distance between ABS k and GUE u. Then, the line of sight probability from ABS k to GUE u is given as,

$$P_{k,u}^{LoS} = a\left(\frac{180}{\pi}\theta_{k,u} - 15\right)^b, \quad (2)$$

where a and b are constant parameters that reflect the environmental conditions. $\theta_{k,u} = \sin^{-1}\left(\frac{h_k}{d_{k,u}}\right)$ is the elevation angle between GUE u and ABS k and we assume that the minimum elevation angle should be 15. Denoting $\lambda = \left(\frac{4\pi f}{c}\right)^2$, the average path loss between ABS k and GUE u is,

$$\tau_{k,u} = \lambda d_{k,u}^2 P_{k,u}^{LoS} \eta_{LoS} + \lambda d_{k,u}^2 P_{k,u}^{NLoS} \eta_{NLoS}. \quad (3)$$

Hence, the SNR of GUE u when it connects to ABS k is,

$$\rho_{k,u} = \frac{P_{k,u}}{\tau_{k,u}\sigma^2}, \quad (4)$$

where σ^2 is the noise power spectral and $P_{k,u}$ is the transmit power of ABS k.

2.2 Ground-Ground Communication Model

For the ground to ground communication link, we consider the macro cell path loss model given in [4],

$$PL_{u,g} = 37.6 \log_{10} d_{u,g} + 15.3 . \quad (5)$$

Then, the SNR of GUE u when it is associated to ground base station is given by,

$$\rho_{u,g} = \frac{P_{u,g} 10^{-PL_{u,g}/10}}{\sigma^2}, \quad (6)$$

where $P_{u,g}$ is the transmit power of ground base station to GUE u.

3. Problem Formulation

In this section, we formulate user association problem as an assignment problem and solve it by using mixed integer programming. The data rate achieved by user $u \in \mathcal{U}$ when it is associated with base station $k \in \mathcal{K}$ is given by,

$$R_{u,k} = B \log_2(1 + \rho_{u,k}), \quad (7)$$

where B is the bandwidth allocated to user u and we assume equal bandwidth allocation among users so that there is no interference. Then, the user association problem is formulated as follows,

$$\max_{\mathcal{A}} \sum_{k=1}^{|\mathcal{K}|} \sum_{u=1}^{|\mathcal{U}|} \delta_{u,k} R_{u,k}, \quad (8)$$

$$\text{s.t} \quad \sum_{k=1}^{|\mathcal{K}|} \delta_{u,k} = 1,\ \forall u \in \mathcal{U}, \quad (9)$$

$$\sum_{u=1}^{|\mathcal{U}|} \delta_{u,k} \le M_k,\ \forall k \in \mathcal{K}, \quad (10)$$

$$\delta_{u,k} \in \{0,1\},\ \forall u \in \mathcal{U},\ k \in \mathcal{K}, \quad (11)$$

where $\mathcal{A}$ is the association matrix. The objective is to maximize the sum rate of the system. Constraint (9) means that each user can be associated with only one base station. The capacity of each base station is demonstrated in constraint (10) and $\delta_{u,k}$ is the decision variable whether user $u \in \mathcal{U}$ is associated to base station $k \in \mathcal{K}$ or not. Since the variable $\delta_{u,k}$ is the integer value (0 or 1), our optimization problem is not convex. Mixed integer programming with cvxpy [5] is adopted to solve our proposed association problem.

4. Simulation Results

In this section, numerical results for our proposed approach are provided. We consider 90000 m^2 area in which there are 35 ground users, 5 aerial small cell base stations and one ground base station. UAVs are hovering at fixed altitude to serve ground users. The altitudes of UAVs and ground base station are 200 m and 20 m respectively. Sub-urban environment with $\eta_{LoS} = 3\ dB$ and $\eta_{NLoS} = 23\ dB$ is considered and the locations of users and base stations are randomly generated for the area of interest. Moreover, the transmit powers of UAVs and ground base station are 1 W and 30 W respectively. The values of a and b are 0.36 and 0.21 respectively [6].

Fig. 2 illustrates the number of associated users to base stations. As we can see in Fig. 2, the number of associated users to ABS_1, ABS_2, ABS_3, ABS_4, ABS_5 and GBS are 7, 3, 4, 4, 7 and 10 respectively. It is obvious that the number of users associated to ground base station is the highest because it has larger capacity to serve more users than UAVs.

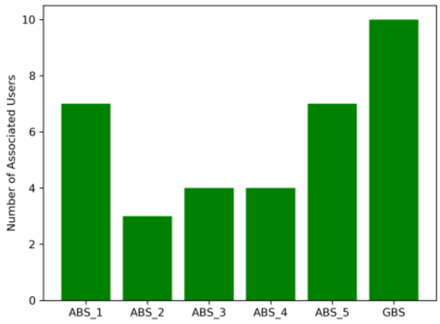

Fig.2. Number of Associated Users to Base Stations.

5. Conclusion

In this paper, we address the association of ground users to either aerial small cell base station or ground base station. We formulate our proposed problem as an assignment problem and apply mixed integer programming with cvxpy to solve it. For our future work, we will investigate the resource allocation problem in space-air-ground integrated network for latency minimization.

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