Coexistence of Aerial and Ground users in UAV-Enabled Wireless Networks

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Abstract

Unmanned Aerial Vehicles (UAVs) which play the roles of communication platforms as well as cellular-connected users have significantly gained great interest in beyond 5G communication. Especially, the networks which integrate aerial users and terrestrial users would offer a number of promising applications and become more realistic. Since the existing cellular networks have been intended for terrestrial users, aerial base stations which can provide better communication links to both aerial and ground users have become a promising solution because of their attributes such as fast deployment, line-of-sight link establishment and so on. One of the key challenges in such integrated network is the association of users (aerial and ground users) to aerial base stations. In this paper, we formulate the user association problem as a transportation problem and solve it by using mixed integer programming.

1. Introduction

Deploying unmanned Aerial Vehicles (UAVs), such as drones and balloons, will be one of the most promising wireless communication platforms for future network. They mainly rely on wireless channels to communicate with ground nodes or nearby aerial communication platforms. Generally, there are two types of communication modes for UAVs; control and non-payload communication and payload communication [1]. In the former case, there is merely a safety-critical information exchange between UAVs and other parties such as an air traffic controller or remote pilots. Transmission or relaying of timely data traffic to/from the ground terminals is done in the other mode.

Whilst UAV base stations are deployed to assist the existing terrestrial network for capacity and coverage enhancement, cellular-connected UAVs can access to the wireless network for mission-related applications such as remote sensing, package delivery, surveillance, and so on. Since the existing cellular base stations are conventionally installed for terrestrial users, other aerial communication platforms which can establish the line of sight communication links to aerial users should be taken into account [2]. Therefore, deploying UAV base stations to serve both aerial and ground users can ensure reliable communication. In this paper, both aerial and ground users are optimally associated with the aerial base stations so that the latency of the network is minimized.

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

2. System Model and Problem Formulation

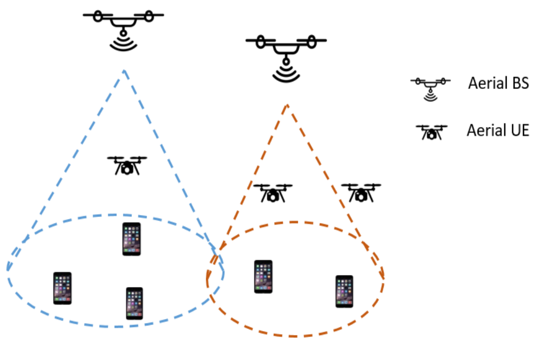

Figure 1. System Model

In our system model, there are M aerial users and N ground users, denoted by $\mathcal{M} = \{1,2,3,\dots,M\}$ and $\mathcal{N} = \{1,2,3,\dots,N\}$ respectively, they are served by a set of aerial base stations $\mathcal{J} = \{1,2,3,\dots,J\}$ in downlink. (x_m, y_m, h_m) and (x_n, y_n, h_n) are the locations of aerial and ground users respectively. Each aerial base station is located at $(x_j, y_j, h_j), j \in \mathcal{J}$ and it adopts the FDMA (Frequency Division Multiple Access) technique while serving its associated users (i.e., both aerial and ground users) [3]. We propose the delayoptimal cell association by exploiting mixed integer programming.

Considering that the aerial users can establish line-of-sight communication links to the aerial base stations, the signal-to-noise ratio of aerial user m which is associated with aerial base station j is given in [2],

$$SNR_{m,j} = \frac{\beta P_{m,j}}{(1+d_{mj})^2 N_0 W_j} \quad (1)$$

where β is a constant factor for path loss and $P_{m,j}$ is the transmit power of aerial base station j. d_{mj} is the Euclidean distance between aerial base station j and its associated aerial user m. W_j is the total bandwidth of aerial base station j and N_0 is the noise power spectral density.

We consider probabilistic line-of-sight path loss model for the aerial to ground communication link between aerial base station and ground users. The path losses for line-of-sight and non-line-of-sight links between aerial base station j and ground user n are given in [4];

$$\zeta_{n,j}^{LoS} = 20\log(\frac{4\pi f}{v}) + 20\log\left(d_{n,j}\right) + \delta_{LoS} \quad (2)$$

$$\zeta_{n,j}^{NLoS} = 20\log(\frac{4\pi f}{v}) + 20\log\left(d_{n,j}\right) + \delta_{NLoS} \quad (3)$$

where f is the carrier frequency. δ_{LoS} and δ_{NLoS} are additional attenuation factors for line-of-sight and non-line-of-sight link respectively. The line of sight probability from ABS j to GUE n can be executed by;

$$P_{n,j}^{LoS} = \frac{1}{1+a\ \exp\left(-b(\alpha_{n,j}-a)\right)} \quad (4)$$

where a and b are constant parameters which depend on the environmental conditions.
Hence, the expected path loss between ABS j and GUE n is;

$$PL_{avg} = \zeta_{n,j}^{LoS} \times\ P_{n,j}^{LoS} + \zeta_{n,j}^{NLoS} \times\ P_{n,j}^{NLoS} \quad (5)$$

Then the SNR of GUE n associated with ABS j is calculated by;

$$SNR_{n,j} = \frac{P_{n,j}}{PL_{avg}\sigma^2} \quad (6)$$

The data rate that ground user n or aerial user m received from aerial base station j is,

$$R_{k,j} = \frac{W_j}{|S_j|}\log_2(1 + SNR_{k,j}),\ \forall k \in \mathcal{M} \cup \mathcal{N} \quad (7)$$

where $|S_j|$ is the number of aerial and ground users associated with ABS j.
Considering the amount of data requirement by each user is τ, the optimization problem is formulated as follows,

$$\min \sum_{j=1}^{J} \sum_{k=1}^{M+N} \delta_{j,k} \frac{\tau}{R_{j,k}} \quad (8)$$

$$\text{s.t } \sum_{k=1}^{M+N} \delta_{j,k} \le D_j,\ \forall j \quad (9)$$

$$\sum_{j=1}^{J} \delta_{j,k} = 1,\ \forall k \in \mathcal{M} \cup \mathcal{N} \quad (10)$$

$$\delta_{j,k} R_{j,k} \ge \gamma, \quad \forall j,\ \forall k \in \mathcal{M} \cup \mathcal{N} \quad (11)$$

$$\delta_{j,k} \in \{0,1\},\ \forall k \in \mathcal{M} \cup \mathcal{N} \quad (12)$$

where constraint (9) captures that the maximum number of users that can be served by each ABS j does not exceed D_j. Furthermore, constraint (10) guarantees that each aerial or ground user can be associated with at most one ABS and (11) ensures the data rate requirement of users. The value of $\delta_{j,k}$ is 1 if user $k \in \mathcal{M} \cup \mathcal{N}$ is associated with ABS j and 0, otherwise. We assume that the locations of all users (aerial and ground users) and ABSs are known to the system.
Since the optimization problem in (8) is an assignment problem, we solve it by using mixed integer programming with cvxpy [5] in which each aerial or ground user is associated to ABS j that can provide minimum latency.

Table 1
Simulation Parameters

Parameter	Description	Value
f	Carrier Frequency	2 GHz
N_0	Noise Power Spectral Density	-170dBm
σ^2	Noise Variance	-96dBm
δ_{LoS}	Attenuation Factor for LoS Link	3 dB
δ_{NLoS}	Attenuation Factor for NLoS Link	23 dB
a, b	Environmental Factors	0.36, 0.21
P	Transmit power of UAV	1 W
τ	Packet Size	10 kb

3. Simulation Results

For the simulation results, a network with 40 ground users, 10 aerial users and 5 UAVs is considered. The size of area is 500 m × 500 m. The height of all aerial base stations is fixed at 200 m. In Fig. 2 and Fig. 3, we illustrate the latency of ground and aerial users respectively. As we can see in Fig. 2, the latency of all aerial users are almost the same. This is because almost all the aerial users are close to their associating aerial BSs. Fig. 3 shows the latency of the ground users. According to Fig. 2 and 3, we can see that the latency of aerial users is lower than that of ground users.

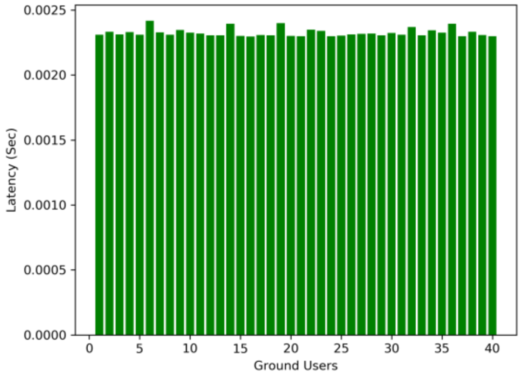

Fig. 2. Latency of Ground Users

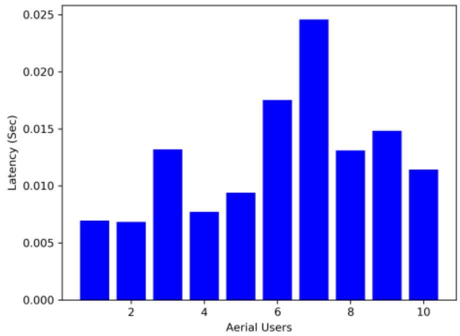

Fig. 3. Latency of Aerial Users

4. Conclusion

In this paper, we address the association of aerial and ground users to aerial base station which can provide low latency. We formulate the assignment problem as transportation problem and solve it by using linear programming. For the future work, we will investigate the sum rate maximization of the network which integrates aerial base station, aerial users, ground base stations and ground users.

Acknowledgement

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