Energy Efficient Resource Allocation in Unmanned Aerial Vehicles-Enabled Wireless Networks

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Abstract

In this paper, the transmit power minimizing of Unmanned Aerial Vehicles (UAVs) which are deployed as aerial base stations is investigated. We assume that the UAVs operate under the frequency division multiple access (FDMA) technique to provide wireless services to the ground users distributed in hotspot area. For the given locations of UAVs and cell association of users, we minimize the transmit power of UAVs under the fair bandwidth allocation satisfying the user data rate requirement using convex optimization. Our analytical results show that the total transmit power of UAVs can be reduced by allocating the bandwidth fairly.

1. Introduction

Unmanned Aerial Vehicles (UAVs), such as drones and balloons, have been used in various applications which contain surveillance and monitoring, military, telecommunications, delivery of medical supplies and rescue operations. However, such conventional UAV-centric research has typically focused on issues of navigation, control, and autonomy, as the motivating applications were typically robotics or military oriented [1]. Due to the advancement of UAVs technology, deploying UAVs as flying aerial base stations becomes a promising solution to extend the wireless coverage and enhance the performance of existing ground wireless networks in terms of capacity, delay and quality of service (QoS) in the areas where the existing terrestrial base stations cannot be fully operational or damaged and in hotspot areas where there are crowded users. They can provide on-the-fly communications and establish line-of-sight (LoS) communication links to the ground users because of their inherent attributes such as mobility, flexibility, and adaptive altitude. They can also be used in public safety scenarios to provide fast and ubiquitous connectivity.

They have many advantages as well as enormous challenges such as air-to-ground channel modeling, trajectory optimization, hover time optimization and energy-efficient deployment. Beyond deployment issues, the energy consumption of UAVs is also an important challenge [3]. In this paper, we contribute to minimize the transmit power of UAVs under the fair bandwidth allocation scheme satisfying the user's data rate requirement by exploiting convex optimization.

The rest of the paper is as follows. In Section 2, we present the system model and problem formulation. We conduct the simulation results in Section 3 and conclude the paper in Section 4.

2. System Model and Problem Formulation

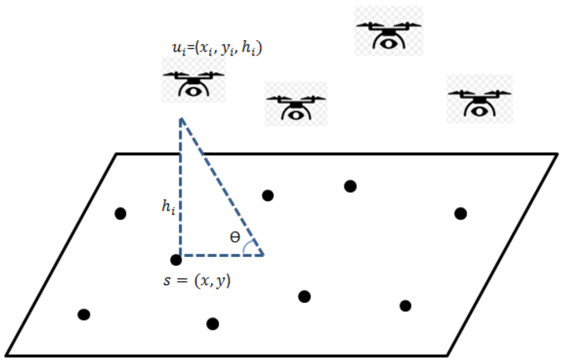

Fig.1. System Model

In our system model, we consider a certain hotspot area in which there are a set $\mathcal{S}_i = \{1, 2, \dots, N\}$ of ground users uniformly distributed in each cell partition D_i of that two-dimensional area and a set $\mathcal{I} = \{1, 2, \dots, I\}$ of UAVs are deployed as aerial base stations to provide wireless services to ground users. Each UAV i will connect with all the users located in the cell D_i. Therefore, the number of UAVs is equal to the number of cell partitions in that area. Among two types of UAVs: fixed wing and rotatory wing, we deploy rotatory wing UAVs because they can hover (stay stationary) in the air. Each cell partition will be serviced by a UAV which adopts FDMA technique to provide wireless service to ground users. Furthermore, we consider the downlink scenario and the area of the cell partitions within that area and locations of UAVs are known. Let $u_i = (x_i, y_i, h_i)$ be the three dimensional coordinates of UAV i and each UAV is located at the altitude of 200m so that it can have line of sight communication links with the user at $s = (x, y)$ in its associated cell.

In our model, we consider each UAV has line of sight communication link with its associated user and the path loss between UAV i and a given user at the location (x, y) is given by [2]:

$$\beta_{i,n} = (\frac{4\Pi f_c d_0}{c})^2 (\frac{d_{i,n}}{d_0})^2 \eta \qquad (1)$$

Where, f_c is the carrier frequency, c is the speed of light, η is the attenuation factor for LoS link and d_0 is the free-space reference distance. $d_{i,n} = \sqrt{(x_n - x_i)^2 + (y_n - y_i)^2 + h_i^2}$ is the distance between UAV i and any given user located at (x, y) in its coverage. We consider that $d_0 = 1m$ and $\lambda = (\frac{4\Pi f_c}{c})^2$.
Hence, the received signal power of a user when it is connected to UAV i is:

$$P_{i,n}^r = \frac{P_{i,n}}{\lambda {d_{i,n}}^2 \eta}, \quad \forall n \in \mathcal{S}_i \qquad (2)$$

Where, $P_{i,n}$ is the transmit power of UAV i to user n.
Considering that all UAVs adopt FDMA technique, the SNR for a user located at (x, y) if it connects with UAV i can be written as:

$$SNR_n^i = \frac{P_{i,n}^r}{n_0}, \quad \forall n \in \mathcal{S}_i \qquad (3)$$

Where, n_0 is the noise power spectral.
The data rate of a user in a cell partition associated by UAV i is given by:

$$R_{i,n} = \frac{\mu B_i}{|\mathcal{S}_i|} \log_2(1 + SNR_n^i), \ \forall n \in \mathcal{S}_i \qquad (4)$$

Where, μ is the bandwidth allocation factor that can be adjusted to control. $|\mathcal{S}_i|$ is the number of users uniformly distributed in cell D_i.
Then the following equation ensures that all the users get equal amount of bandwidth [2].

$$\frac{B_i}{|\mathcal{S}_i|} = \frac{B_j}{|\mathcal{S}_j|} \quad \forall i \neq j \qquad (5)$$

Now, we formulate our optimization problem to minimize the total transmit power of UAVs as follows:

$$\min_{P_{i,n}} \sum_{i=1}^{I} \sum_{n=1}^{N} P_{i,n} \qquad (6)$$

$$\text{s.t } R_{i,n} \geq r, \quad \forall i, n \in \mathcal{S}_i \qquad (7)$$

$$\sum_{n=1}^{N} P_{i,n} \leq P_{max}, \quad \forall i \qquad (8)$$

Where, the constraint (7) ensures that each user meets its data rate requirement and (8) guarantees that the total transmit power of UAV i which serves the numbers of users in its footprint does not exceed its maximum power.

Simulation Parameters

Parameter	Description	Value
f_c	Carrier frequency	2 GHz
n_0	Noise power spectral	−170 dBm/Hz
η	Attenuation factor for LoS link	3 dB
B	Bandwidth of each UAV	1 MHz
h	Altitude	200 m
r	Date rate requirement per user	1 Mbps

3. Simulation Results

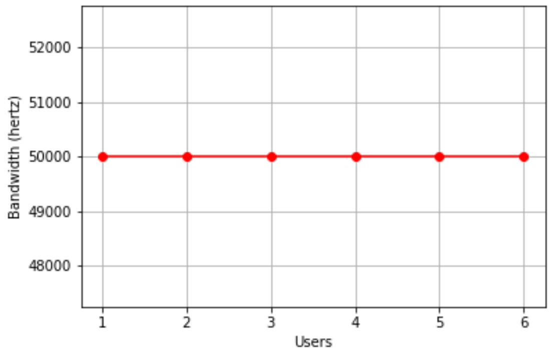

Fig.2. Bandwidth Versus Users

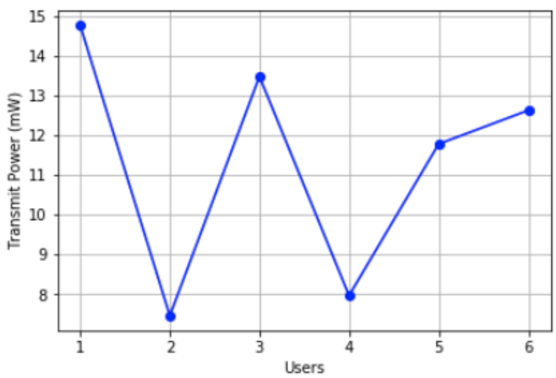

Fig.3. Transmit Power and Users

In figure.2, we can see that every user gets the equal amount of bandwidth. Figure.3 illustrates that transmit power of UAV i to its users within its cell partition. Using convex optimization, we obtain the optimal transmit powers of UAV i to the users which are uniformly distributed in a given cell partition.

4. Conclusion

In this paper, we employed the convex optimization to minimize the total transmit power of UAV under the fair allocation of bandwidth satisfying the user's data rate requirement by considering that UAV has LoS communication link with the user. For our future work, we will investigate how to maximize the throughput of users by taking into account the mobility of UAVs and the effective user association.

Acknowledgement

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