The Energy-efficient UAV-based BS Coverage in Air-to-Ground Communications

Bin Li, Chao Chen, Ruonan Zhang, Hong Jiang, Xianzhen Guo

Department of Communication Engineering, Northwestern Polytechnical University, Xi'an, China 710072

I. Introduction

With the increasing trend of unmanned aerial vehicles (UAVs) applications, UAV-based base station(BS) has gained significant popularity for rapid deployable networks. In practice, to achieve high-speed or reliable wireless communications with the UEs, the flight altitude of UAVs is not very high in the consideration of the limited power supply and the path loss (PL). On the other hand, if the flight altitude is too low, the multi-paths generated by the earth surface or buildings may cause non-light of sight (NLoS) fading affect, leading to the lower capacity for the given transmitting power and the limitation of the coverage size. Therefore, it is worth to explore the flight altitude property in the low-altitude scenarios, so as to maximize the coverage size. In addition, the directional antenna equipped at the UAV is also an important fact for air-to-ground communications. In order to improve the energy-efficiency under the limited power supply in UAV, the directional antennas are always selected to focus the transmitting power to the ground coverage. Intuitively, under the given transmitting power and the flight altitude, when the beam angle is small, although each UE has the good signal quality in the coverage area, the coverage radius is short, which greatly constrains the communications service. If the UAV selects the larger beam angle to expand the radio coverage, the transmitting power will be diluted in the air, causing the lower signal noise ratio (SNR) or capacity in the coverage. Under this situation, the effective coverage area in which the capacity is larger than the threshold is also limited. Therefore, selecting the appropriate flight altitude and beam angle to maximize the coverage area is a important problem in the UAV communications.

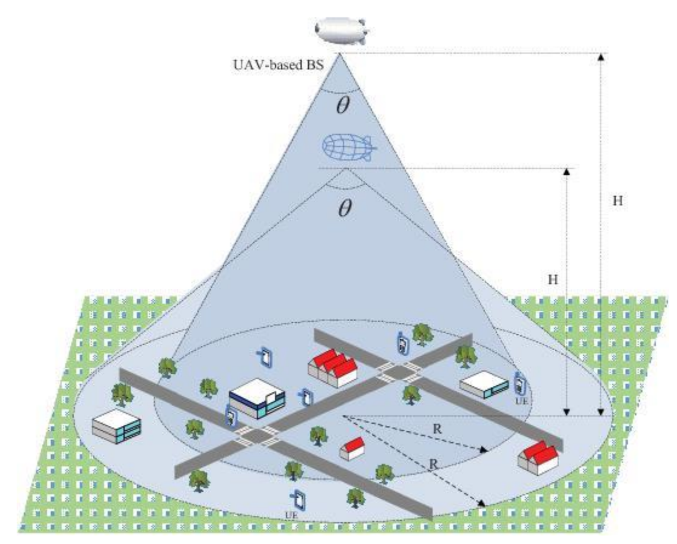

Fig. 1 System model: the aerial base station (ABS) equips the directional antenna and hovers over the UEs to provide the communication service with different altitudes and coverage sizes.

II. Analysis

Here we consider a typical low altitude coverage scenario wherein one UAV hovers in the air to provide the wireless coverage for the UEs on the ground. The flight altitude is set as H and the beam angle of the directional antenna equipped at the UAV is denoted by Θ, for the purpose of the energy-efficiency. To guarantee the basic wireless channel capacity in the coverage area, we set a capacity threshold C_{th} to decide the effective coverage area, out of which the UAV can not communicate with the UEs, as shown in fig. 1. In detail, the air-to-ground channel is modeled by the equation:

$$PL = \frac{\mu_{LoS} - \mu_{NLoS}}{1 + a\exp(-b[\frac{\pi}{2} - \tan(\frac{R}{H}) - a])} + 10\lg(H^2 + R^2) + 20\lg f + 20\lg(\frac{4\pi}{c}) + \mu_{NLOS} \quad (1)$$

Where μ_{LoS} and μ_{NLoS} are the mean additional losses for light of sight (LoS) and non-light of sight (NLoS). Here NLoS is caused by the obstacle between the transceivers under low altitude communications. The value of (μ_{LoS}, μ_{NLoS}) pair is different under different kinds of scenarios. f shows the carrier frequency. R denotes the coverage radius. a and b can be calculated by the following equation:

$$z = \sum_{j=0}^{3}\sum_{i=0}^{3-j} C_{ij}(\alpha\beta)^i \gamma^j \quad (2)$$

where z represents a or b. (α,β,γ)=(0.1, 750, 8) for suburban scenario [11]. According to the above equations, for the same transmitting distance, when the UAV has the lower flight altitude, the PL will be larger than that for the higher altitude. This is because the radio signals in lower altitude situation could easily affected by the obstacle, such as trees or buildings on the ground, causing the higher PL.

On the other hand, according to the antenna property [2],the relationship between the antenna gain and the angle of the sector antenna can be approximately expressed as:

$$G_a(dBi) = 10lg\left(9.7 / (\theta_{E,3dB} \times \theta_{H,3dB})\right) \quad (3)$$

where $\theta_{E,3dB}$ and $\theta_{H,3dB}$ are the elevational angle and horizontal angle of the 3dB gain. To maximize the wireless coverage, we set $\theta_{E,3dB} = \theta_{H,3dB}$=Θ. Meanwhile, for easily calculation, we also make the assumption that when the UEs are out of the antenna beam, they can not get the reliable links with the UAV.

For the given H and θ ≤ Θ, the transmitting distance between the UAV and UE n in the antenna beam is H/cos(θ). According to the channel model in Eq. 1 and antenna gain in Eq. 3, we can get the received SNR by n is shown as:

$$\Gamma_n(H,\theta) = 10lg(P) - G_a(\theta) - PL(H,\theta) \quad (4)$$

where Γn denotes the SNR with dB, and is affected by H and θ. For the value of Ga(θ),if θ ≤ Θ, Ga(θ) follows Eq.3. Otherwise, Ga(θ)=0.Therefore, the capacity between UAV and n is

$$C(H,\Theta,\theta) = lg(1 + 10^{\frac{\Gamma_n/10}{\sigma^2}}) \quad (5)$$

where σ^2 denotes the noise power. We use effective radius of radiation to quantify effective coverage area. To maximize the effective coverage area in which C>C_{th}, we must adjust H and Θ synchronously under the given transmitting power P. Obviously, it is a typical joint 2-D optimization problem and can be formulated as:

$$\begin{aligned}
&\arg\max_{H,\Theta} R = H\tan(\theta_{th}) \\
&Subject\ to: \\
&C(H,\Theta,\theta_{th}) = C_{th}, \\
&C(H,\Theta,\theta) \geq C_{th} \quad for \quad \theta \leq \theta_{th}, \\
&P \leq P_{max}, \\
&\theta_{th} \leq \Theta, \\
&0 < \Theta < \pi;
\end{aligned}$$

III. Simulation Results

Here we utilize the particle swarm optimization (PSO) [3] to find the optimal solution by 2-dimensional search.

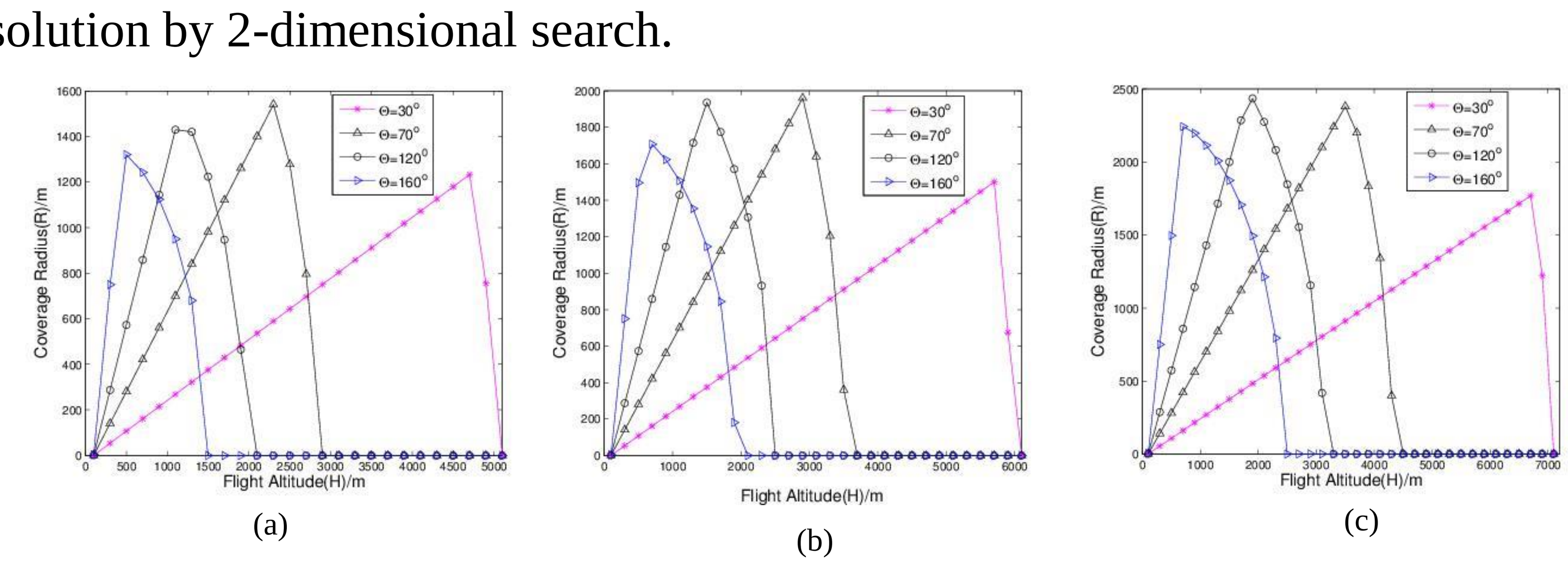

Fig. 2: The coverage radius vs. the flight altitude H. (a) P =27dBm; (b) P =30dBm; (c) P =33dBm

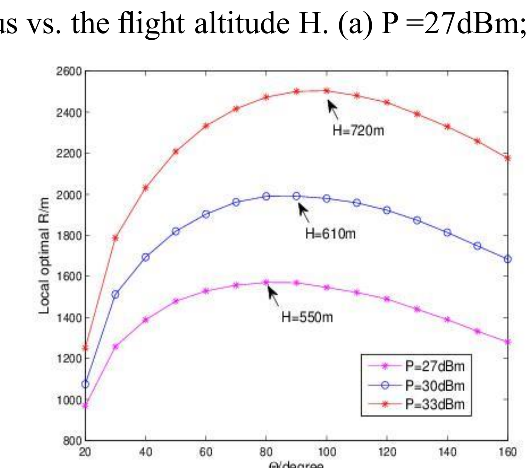

Fig. 3: The local optimal R vs. Θ

IV. Conclusion

In this paper, we proposed the energy-efficient coverage strategy for UAV-based BS under the constraint of the transmitting power. After modeling the air-to-ground channel in low altitude scenario, we set up the relationship between the antenna beam angle and antenna gain. Finally, we formulated the coverage problem as the 2-D optimization, and found the optimal parameters by introducing PSO to find the optimal solution.

V. Reference

[1] M. Mozaffari, W. Saad, M. Bennis, and M. Debbah, "Unmanned aerial vehicle with underlaid device-to-device communications: Performance and tradeoffs," IEEE Transactions on Wireless Communications , vol. 15,no. 6, pp. 3949–3963, 2016.

[2] D. K. Cheng, "Field and wave electromagnetics: Pearson new interna-tional edition," Pearson Schweiz Ag , 2013.

[3] Y. Shi and R. C. Eberhart, "Empirical study of particle swarm op-timization," in Proceedings of the 1999 Congress on Evolutionary Computation-CEC99, vol. 3, 1999, p. 1950 Vol. 3.