Jointly Optimizing Drone-Mounted Base Station Placement and User Association in Heterogeneous Networks

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***Abstract*—Applying Drone-mounted Base Station (DBS) to assist Macro Base Station (MBS) can potentially increase the throughput of the mobile access network. In this paper, we first derive the spectral efficiency of delivering traffic from the MBS to a Ground User (GU) via the DBS, which is operated in the half-duplex in-band mode, upon which we formulate the problem by jointly optimizing the DBS placement (i.e., the altitude of the DBS) and user association in order to maximize the spectral efficiency of the hotspot area. We design the Spectral efficienT Aware DBS pLacement and usEr association (STABLE) algorithm to solve the proposed problem and demonstrate the performance of STABLE via simulations.**

***Index Terms*—Drone base station, spectral efficiency, user association, mobile network**

I. Introduction

A drone is an Unmanned Aerial Vehicle (UAV) that is designed to be flown under remote control or autonomously using embedded software and sensors (e.g., GPS) [1]. Equipped drones with small cell base stations facilitate mobile network providers to deliver flash crowd traffic to Ground Users (GUs) in hotspots [2]. Specifically, a Drone-mounted Base Station (DBS) can serve as a relay node to deliver traffic from its connected Macro Base Station (MBS) to the GUs, which are associated with the DBS. Different from traditional small cells (whose locations are normally fixed), DBSs have been identified with their unique advantages, i.e., faster and cheaper to deploy, more flexibly reconfigured, and likely to have better communications channels owing to the presence of short-range Line-of-Sight (LoS) links [3]. These features enable DBSs to be quickly deployed to the random hotspots in the network to increase the data rate of the GUs in the hotspot areas.

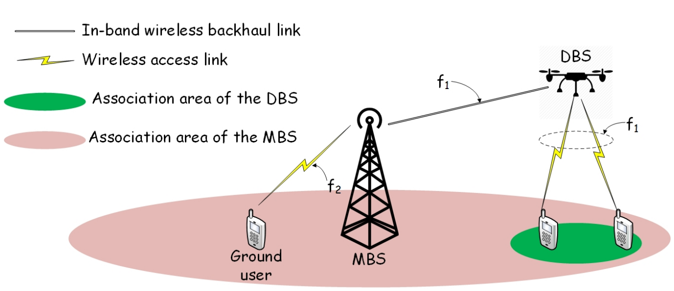


Fig. 1: DBS aided mobile access network.

In this paper, we consider one Macro Base Station (MBS) and one DBS that coexist in the network. The DBS is deployed to improve the throughput of GUs in the hotspot area. The DBS is operated in the in-band half-duplex mode [4]–[7] to relay traffic from the MBS to the GUs. The in-band half-duplex mode means that the DBS uses the same band to download traffic from the MBS (i.e., wireless backhaul links) and relay traffic to the GUs (i.e. access network links). As shown in Fig. 1, the band of f_1 is applied to download traffic from the MBS to the GUs (which are associated with the DBS) via the DBS. Note that Time-Division Multiplexing(TDM) is used to schedule the transmission in wireless backhaul links and wireless access links; meanwhile, the band of f_2 is utilized to directly download traffic from the MBS to the GUs (which are associated with the MBS) in order to avoid the interference. Note that the horizontal geolocation of the DBS is determined based on the existing methods (e.g., placing the DBS at the center of a hotspot area or based on the traffic demands of different locations [8]). Based on the above assumptions, this paper addresses the following problems:

- **What is the optimal altitude of the DBS to maximize the spectral efficiency of the GUs [1] in the hotspot area?** Two wireless links, i.e., wireless backhaul link and wireless access link, are used to deliver traffic from the MBS to a GU (which is associated to the DBS). In order to maximize the spectral efficiency of downloading traffic from the MBS to the GU via the DBS, the altitude of the DBS should be optimized by jointly considering the spectral efficiency of the wireless backhaul link as well as the wireless access link. Note that it is nontrivial to find the optimal altitude of the DBS because the DBS with lower altitude provides shorter distance to the GUs, which may potentially reduce the path loss from the DBS to the GUs, and thus increase the spectral efficiency of the wireless access link; however, the DBS with lower altitude incurs higher probability of None Line-of-Sight (NLoS) to the GUs [9]–[12], which may potentially increase the path loss from the DBS to the GUs, and

[1]The spectral efficiency (bps/Hz) of the GUs refers to the amount of traffic that can be delivered to the GUs per unit of bandwidth. Higher spectral efficiency normally indicates higher throughput (i.e., higher data rate of downloading traffic to the GUs). Thus, we use the spectral efficiency to measure the performance of the network in the paper.

thus reduce the spectral efficiency. In addition, the optimal altitude of the DBS varies among GUs, i.e., the altitude of the DBS, which incurs the maximum spectral efficiency between the DBS and a GU, may not be the optimal altitude with respect to another GU. How to determine the optimal altitude of the DBS to maximize the total spectral efficiency between the DBS and all the GUs in the hotspot area is the problem to be addressed in the paper.

- **What is the best user association strategy?**
There are two BSs, i.e., MBS and DBS, in the access network. GUs in the hotspot area can essentially associate with either one to download their traffic. In order to maximize the data rate of downloading traffic, a GU would select the BS, which provisions better spectral efficiency. However, the spectral efficiency between the DBS and a GU is related to the altitude of the DBS, i.e., choosing a different altitude of the DBS may incur a different spectral efficiency between the DBS and a GU, thus resulting in the GU associating with a different BS. Essentially, the user association problem and the DBS placement problem[2] are coupled, thus making the whole problem difficult to solve.

The contributions of the paper include:

1) We model the spectral efficiency of delivering traffic from the MBS to a GU via the DBS by jointly considering the spectral efficiency of the wireless backhaul link and the wireless access link, upon which we propose a method to determine the optimal altitude of the DBS in order to maximize the spectral efficiency of delivering traffic from the MBS to the GU via the DBS.
2) We formulate the problem to maximize the total spectral efficiency for the GUs in the hotspot area by jointly optimizing the DBS placement and user association.
3) We design the Spectral efficienT Aware DBS pLacement and usEr association (STABLE) algorithm to efficiently solve the proposed problem and demonstrate the performance of STABLE via simulations.

II. Related works

Various works have identified the great potential to improve the performance of the access network by applying DBSs to assist the existing mobile BSs [3], [8], [13]. In order to further enhance the performance, DBSs should be optimally deployed. Al-Hourani *et al.* [9] derived the optimal altitude of a DBS, which is a function of the maximum allowed pathloss and the statistical parameters of the urban environment, to maximize the radio coverage on the ground. Yaliniz *et al.* [14] proposed a DBS placement problem to determine the altitude and the user association area of a DBS such that the DBS can cover as many GUs as possible, while satisfying the QoS requirement (in terms of the path loss from the DBS to the GU being less than a predefined path loss threshold) for each GU, which is associated to the DBS. Given the altitude of the DBS, Sun and Ansari [8] designed a strategy to jointly optimize the user association and 2D DBS placement in order to minimize the average delay of delivering traffic to GUs. Azade *et al.* [10] designed a DBS repositioning method to move the DBS in the direction that achieves the largest spectral efficiency gain during a time slot. Here, the spectral efficiency gain indicates the average spectral efficiency difference between the DBS and the MBS for serving the GUs.

Note that all the mentioned DBS placement and the user association solutions do not consider the spectral efficiency of the wireless backhaul links and they try to enable the DBS to accommodate more GUs in the access links; however, we argue that the usage of the DBS is to primarily maximize the throughput (i.e., the spectral efficiency) of the GUs within the hotspot area only. Thus, in this paper, we jointly optimize the altitude of the DBS and user association by considering the spectrum efficiency of wireless access links as well as wireless backhaul links such that the total spectral efficiency of the GUs in the hotspot area is maximized.

III. System model

We consider the scenario shown in Fig. 1 in which the horizontal location of the DBS is given and the in-band half-duplex mode is applied by the DBS.

A. Spectral Efficiency

The whole radio coverage of the MBS is divided into a number of locations with the same size. Denote $\mathcal{I}$ as the set of these locations and i is used to index these locations. The overall spectral efficiency of an area is defined as the sum of the spectrum efficiency of each location[3] in the area, i.e.,

$$\varphi = \sum_{i \in \mathcal{I}'} \varphi_i, \tag{1}$$

where φ_i is the spectral efficiency of location i and $\mathcal{I}'$ (where $\mathcal{I}' \subset \mathcal{I}$) is the set of the locations in the area. Note that higher overall spectral efficiency of the area implies that higher data rate of the GUs in the area can be achieved.

Traffic of the GUs in location i can be delivered directly from the MBS or delivered from the MBS via the DBS, and so the spectral efficiency of location i can be derived for two different scenarios.

1) If traffic of GUs in location i is directly delivered by the MBS, according to the Shannon Capacity Theorem, the spectral efficiency of location i can be formulated as

$$\varphi_i^m = \log_2 \left(1 + \frac{p^m g_i^m}{\sigma^2}\right), \tag{2}$$

where φ_i^m is the spectral efficiency of enabling the MBS in delivering traffic to the GUs in location i, p^m is the maximum transmission power of the MBS, σ^2 denotes the noise power level, and g_i^m is the channel gain between the MBS and the GUs in location i. Note that g_i^m can be measured by the MBS in a large time scale [15], [16].

[2]The DBS placement problem is referred to as the problem of determining the altitude of the DBS.

[3]The spectrum efficiency of a location refers to the amount of traffic that can be transmitted to the GUs in the location per unit of bandwidth.

2) If traffic of the GUs in location i is delivered by the MBS via the DBS, the spectral efficiency of location i can be obtained based on the following lemma.

Lemma 1. Denote the channel gain between the MBS and the DBS as $g^{m\to d}$ and the channel gain between the DBS and the GUs in location i as $g_i^{d\to u}$, respectively. If traffic of GUs in location i is delivered by the MBS via the DBS, the spectral efficiency of location i is

$$\varphi_i^d = \frac{1}{\frac{1}{\log_2\left(1+\frac{p^m g^{m\to d}}{\sigma^2}\right)} + \frac{1}{\log_2\left(1+\frac{p^d g_i^{d\to u}}{\sigma^2}\right)}}, \qquad (3)$$

where φ_i^d is the spectral efficiency of enabling the DBS in delivering traffic from the MBS to the GUs in location i and p^d is the maximum transmission power of the DBS.

Proof: As mentioned previously, TDM is used to schedule the transmission in wireless backhaul and wireless access links if in-band half-duplex mode is used in the DBS. Assume that the total amount of bandwidth for delivering the data to the GUs in location i is B. The data rate of the MBS in downloading traffic to the DBS is $B\log_2\left(1+\frac{p^m g^{m\to d}}{\sigma^2}\right)$. If ω amount of data need to be delivered to the GUs in location i, the time for transmitting ω amount of data from the MBS to the DBS is $t^{m\to d} = \frac{\omega}{B\log_2\left(1+\frac{p^m g^{m\to d}}{\sigma^2}\right)}$. Similarly, the time for transmitting ω amount of data from the DBS to the GUs in location i is $t_i^{d\to u} = \frac{\omega}{B\log_2\left(1+\frac{p^d g_i^{d\to u}}{\sigma^2}\right)}$, where $B\log_2\left(1+\frac{p^d g_i^{d\to u}}{\sigma^2}\right)$ is the data rate of the DBS in downloading traffic to the GUs in location i. Thus, the total time for transmitting ω amount of data from the MBS to the GUs in location i via the DBS can be derived as

$$\begin{aligned} t &= t^{m\to d} + t_i^{d\to u} \\ &= \frac{\omega}{B\log_2\left(1+\frac{p^m g^{m\to d}}{\sigma^2}\right)} + \frac{\omega}{B\log_2\left(1+\frac{p^d g_i^{d\to u}}{\sigma^2}\right)}. \end{aligned}$$

Hence, the spectral efficiency of location i by enabling the DBS in delivering traffic is

$$\varphi_i^d = \frac{\omega}{tB} = \frac{1}{\frac{1}{\log_2\left(1+\frac{p^m g^{m\to d}}{\sigma^2}\right)} + \frac{1}{\log_2\left(1+\frac{p^d g_i^{d\to u}}{\sigma^2}\right)}}. \qquad (4)$$

■

Note that the values of $g^{m\to d}$ and $g_i^{d\to u}$ in Eq. 3 are not known and we need to estimate them (which may vary by selecting different altitudes of the DBS) in order to obtain φ_i^d. The channel gain between the MBS and the DBS (i.e., $g^{m\to d}$), and between the DBS and the GUs (i.e., $g_i^{d\to u}$) in location i are mainly determined by their average path loss values[4], i.e.,

$$g^{m\to d} = 10^{\frac{-\eta^m}{10}}, \; g_i^{d\to u} = 10^{\frac{-\eta_i^d}{10}}, \qquad (5)$$

where η^m and η_i^d are the average path loss between the MBS and the DBS, and between the DBS and the GUs in location i, respectively. We will build models to estimate η^m and η_i^d, respectively, in the next section.

[4]For a clear exposition, the shadowing and fading effects are not considered.

B. Average path loss model between the DBS and GUs

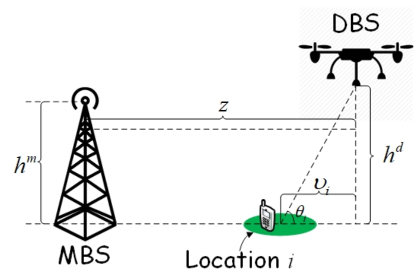


Fig. 2: The position of the DBS.

The wireless propagation channel between the DBS and the GUs in location i is modeled by a probabilistic LoS channel, and the probability of having an LoS connection between the DBS and the GUs in location i is [9]

$$\rho_i = \frac{1}{1+\alpha_i e^{-\beta_i(\theta_i-\alpha_i)}}, \qquad (6)$$

where α_i and β_i are the Sigmoid curve parameters, which are determined by the environment in location i and can be measured proactively; θ_i is the angle (in degree) between the DBS and location i, which is described in Fig. 2. Denote the height of the DBS as h^d and the horizontal distance between the DBS and location i as υ_i; then, θ_i can be expressed as

$$\theta_i = \arctan\left(\frac{h^d}{\upsilon_i}\right). \qquad (7)$$

Denote η_i^{los} and η_i^{nlos} as the path loss (in dB) between the DBS and the GUs in location i with an LoS connection and NLoS connection, receptively. η_i^{los} and η_i^{nlos} can be calculated by [17]

$$\eta_i^{los} = \xi^{los} + \gamma^{los}\log_{10}\left(\sqrt{(\upsilon_i)^2+(h^d)^2}\right), \qquad (8)$$

$$\eta_i^{nlos} = \xi^{nlos} + \gamma^{nlos}\log_{10}\left(\sqrt{(\upsilon_i)^2+(h^d)^2}\right), \qquad (9)$$

where ξ^{los} and ξ^{los} are the path loss at the reference distance under an LoS connection and NLoS connection, respectively, and γ^{los} and γ^{nlos} are the path loss exponents under an LoS connection and NLoS connection, respectively. All of these parameters can be proactively obtained from field tests [17]. $\sqrt{(\upsilon_i)^2+(h^d)^2}$ indicates the 3-D distance between the DBS and location i. Therefore, the average path loss between the DBS and the GUs in location i can be estimated by Eq. (10).

C. Average path loss model between the MBS and the DBS

Denote h^{min} as the lowest altitude of the DBS to guarantee the channel between the MBS and the DBS to be an LOS channel; thus, if $h^d \geq h^{min}$, the propagation channel between the MBS and the DBS is an LOS channel, and thus the average path loss between the MBS and the DBS is

$$\eta_i^d = \rho_i \eta_i^{los} + (1-\rho_i)\,\eta_i^{nlos}$$
$$= \frac{1}{1+\alpha_i e^{-\beta_i\left(\arctan\left(\frac{h^d}{\upsilon_i}\right)-\alpha_i\right)}}\left(\xi^{los}+\gamma^{los}\log_{10}\left(\sqrt{(\upsilon_i)^2+(h^d)^2}\right)\right)+\left(1-\frac{1}{1+\alpha_i e^{-\beta_i\left(\arctan\left(\frac{h^d}{\upsilon_i}\right)-\alpha_i\right)}}\right)\left(\xi^{nlos}+\gamma^{nlos}\log_{10}\left(\sqrt{(\upsilon_i)^2+(h^d)^2}\right)\right). \quad (10)$$

$$\eta^m = \xi^{los} + \gamma^{los}\log_{10}\left(\sqrt{(z)^2+(h^d-h^m)^2}\right), \quad (11)$$

where z is the horizontal distance between the MBS and the DBS, h^m is the altitude of the MBS (which is fixed), and $\sqrt{(z)^2+(h^d-h^m)^2}$ indicates the 3-D distance between the MBS and the DBS.

TABLE I: Parameters in Numerical Analysis

Parameter	Definition	Value
h^m	Altitude of MBS	10 m
ξ^{los}	Path loss offset (LoS)	103.4 dB
γ^{los}	Path loss exponent (LoS)	24.2 dB/km
ξ^{nlos}	Path loss offset (NLoS)	131.4 dB
γ^{nlos}	Path loss exponent (NLoS)	42.8 dB/km
σ^2	Noise	-104 dBm
p^m	Transmission power of the MBS	46 dBm
p^d	Transmission power of the DBS	24 dBm
α, β	Sigmoid curve parameters	11.95, 0.136
h^{min}	Minimum Altitude of DBS	10 m
h^{max}	Maximum Altitude of DBS	1 km

D. Optimal altitude of the DBS with respect to a location

By substituting Eq. (5) into Eq. (3), we can obtain the spectral efficiency for the DBS to transmit traffic to the GUs in location i:

$$\varphi_i^d = \frac{1}{\frac{1}{\log_2\left(1+\frac{p^m 10^{\frac{-\eta^m}{10}}}{\sigma^2}\right)}+\frac{1}{\log_2\left(1+\frac{p^d 10^{\frac{-\eta_i^d}{10}}}{\sigma^2}\right)}}, \quad (12)$$

where η_i^d and η^m are the functions of h_d (i.e., Eq. (10) and Eq. (11)). Consider the scenario that the DBS is placed 500 meters away from the MBS (i.e., $z = 500\ m$). Based on the system setup in Table I, we obtain the numerical results of φ_i^d by varying the altitude of the DBS (i.e., h_d) and the horizontal distance between the DBS and a location (i.e., υ_i). As shown in Fig. 3, if the altitude of the DBS is fixed, the spectral efficiency decreases as the horizontal distance between the DBS and the location decreases; however, if the horizontal distance between the horizontal distance between the DBS and the location is fixed, the spectral efficiency of the location does not monotonically increase/decrease as the altitude of the DBS increases. Fig. 4 shows the spectral efficiency of three different locations (whose the horizontal distance to the DBS is 100 m, 200 m, and 300 m, respectively) by varying the altitude of the DBS. Each location with the optimal altitude of the DBS achieves the highest spectral efficiency in terms of the largest value of φ_i^d. The optimal altitude of the DBS is varied by selecting different locations. Note that the optimal altitude of the DBS for location i, denoted as h_i^*, can be obtained by searching for the value of h^d that satisfies the equation of the critical point (i.e., $\frac{\partial \varphi_i^d}{\partial h^d} = 0$)[5].

IV. Problem Formulation

The DBS is normally placed in a hotspot area to improve the spectral efficiency of the locations in this hotspot area. Denote $\boldsymbol{\mathcal{A}}$ as the hotspot area, where $\boldsymbol{\mathcal{A}} \subset \boldsymbol{\mathcal{I}}$, and we formulate the problem to maximize the total spectral efficient of the locations in $\boldsymbol{\mathcal{A}}$ by jointly optimizing the DBS placement and user association, i.e.,

$$\boldsymbol{P0}: \underset{h^d,\boldsymbol{\mathcal{X}}}{argmin} \sum_{i\in\boldsymbol{\mathcal{A}}} \left(\varphi_i^d x_i + \varphi_i^m (1-x_i)\right) \quad (13)$$
$$s.t. \quad h^{\min} \le h^d \le h^{\max}, \quad (14)$$
$$\forall i \in \boldsymbol{\mathcal{A}}, x_i \in \{0,1\}, \quad (15)$$

where h^{max} is the highest altitude that the DBS can reach, x_i ($i \in \boldsymbol{\mathcal{A}}$) is a binary variable to indicate whether the GUs in location i is associated with the DBS (i.e., $x_i = 1$) or not (i.e., $x_i = 0$) and $\boldsymbol{\mathcal{X}} = \{x_i \,|i \in \boldsymbol{\mathcal{A}}\}$. The objective of $\boldsymbol{P0}$ is to maximize the total spectral efficiency of all the locations in the hotspot area $\boldsymbol{\mathcal{A}}$. Constraint (14) imposes the maximum and minimum altitude of the DBS.

Note that φ_i^m is independent with respect to h^d. Thus, $\boldsymbol{P0}$ can be transformed into

$$\boldsymbol{P1}: \underset{h^d,\boldsymbol{\mathcal{X}}}{argmin} \sum_{i\in\boldsymbol{\mathcal{A}}} \left(\varphi_i^d - \varphi_i^m\right) x_i \quad (16)$$
$$s.t. \quad Constraints\ (14)\ and\ (15).$$

The optimal value of $\boldsymbol{\mathcal{X}}$ of $\boldsymbol{P1}$ can be easily derived, i.e.,

$$x_i = \begin{cases} 1, & \varphi_i^d > \varphi_i^m. \\ 0, & \varphi_i^d \le \varphi_i^m. \end{cases} \quad (17)$$

Denote $\boldsymbol{\mathcal{B}}$ as the user association area of the DBS, i.e., $\boldsymbol{\mathcal{B}} = \{i \in \boldsymbol{\mathcal{A}} | x_i = 1\}$. Thus, $\boldsymbol{P1}$ can be further transformed into

$$\boldsymbol{P2}: \underset{h^d}{argmin} \sum_{i\in\boldsymbol{\mathcal{B}}} \varphi_i^d \quad (18)$$
$$s.t. \quad Constraint\ (14).$$

V. Spectral efficienT Aware DBS pLacement and usEr association (STABLE)

Solving $\boldsymbol{P2}$ is not trivial because adjusting the value of h^d may vary the values of φ_i^d and $\boldsymbol{\mathcal{X}}$ simultaneously. Thus, we design the **S**pectral efficien**T** **A**ware D**B**S p**L**acement and

[5] Various methods (e.g., the gradient method) can be used to find the critical point.

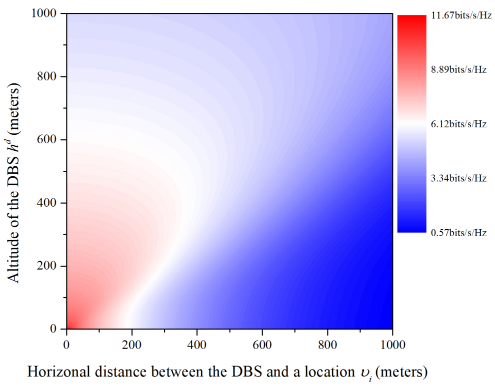


Fig. 3: The spectral efficiency of a location by varying the values of h^d and υ_i.

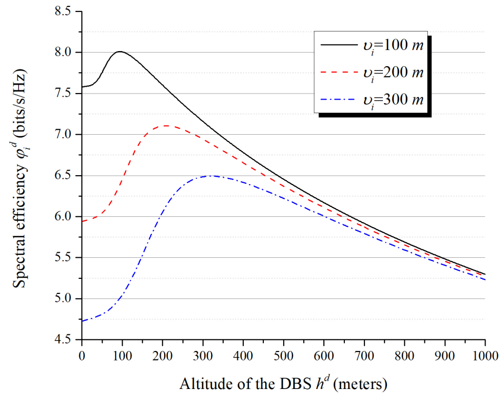
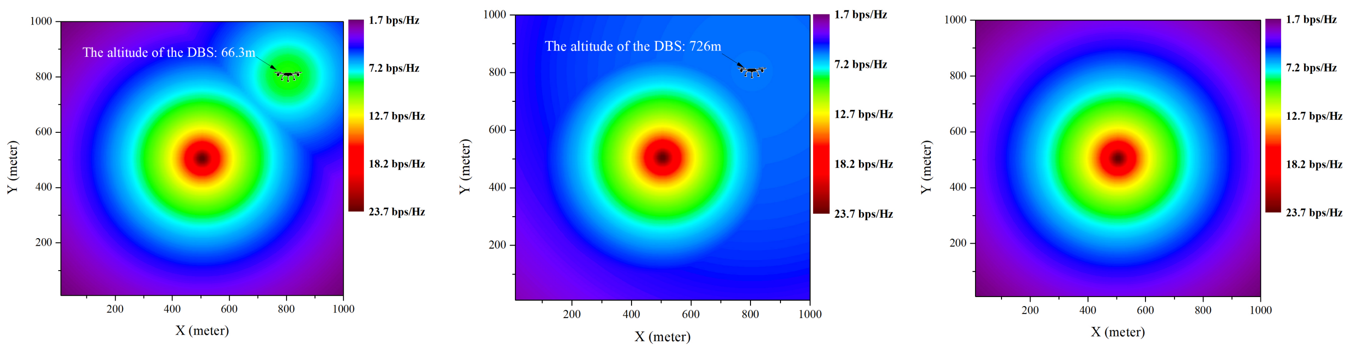


Fig. 4: The spectral efficiency of three locations by varying the altitude of the DBS.



(a) STABLE.

(b) C-DBS.

(c) S-MBS.

Fig. 5: The spectral efficient of different locations of the network.

Algorithm 1 STABLE algorithm

1: $\forall i \in \boldsymbol{\mathcal{A}}$, calculate h_i^* and φ_i^m.
2: Initialize $\boldsymbol{\mathcal{X}} = \mathbf{0}$ and $\varphi^{max} = 0$.
3: Set up $x_N = 1$ and $\boldsymbol{\mathcal{B}} = \{N\}$.
4: Calculate φ_N^d based on Eq. (12).
5: Calculate $\varphi = \sum_{i \in \boldsymbol{\mathcal{B}}} \varphi_i^d = \varphi_N^d$.
6: Initialize $h^d = h_N^*$.
7: **while** $\varphi^{max} < \varphi$ **do**
8: $\quad \varphi^{max} = \varphi$ and $h = h^d$;
9: $\quad$ Update $\boldsymbol{\mathcal{X}}$ based on Eq. (17);
10: $\quad$ Update $\boldsymbol{\mathcal{B}} = \{i | x_i = 1\}$;
11: $\quad$ Update the value of h^d based on Eq. (19);
12: $\quad$ Update φ_i^d ($\forall i \in \boldsymbol{\mathcal{B}}$) based on Eq. (12);
13: $\quad$ Calculate $\varphi = \sum_{i \in \boldsymbol{\mathcal{B}}} \varphi_i^d$.
14: **end while**
15: **return** h and $\boldsymbol{\mathcal{X}}$

us**E**r association (STABLE) algorithm, which is summarized in Algorithm 1, to efficiently solve $\boldsymbol{P2}$. The basic idea of STABLE is to select the altitude of the DBS (i.e., h^d) given the user association area $\boldsymbol{\mathcal{B}}$ in each iteration until the total spectral efficiency of user association area $\boldsymbol{\mathcal{B}}$ cannot be increased. Here, h^d equals to the weighted average of the value of h_i^* (i.e., the optimal altitude of the DBS with respect to location i) for all $i \in \boldsymbol{\mathcal{B}}$, i.e.,

$$h^d = \frac{1}{|\boldsymbol{\mathcal{B}}|} \sum_{i \in \boldsymbol{\mathcal{B}}} \omega_i h_i^*, \tag{19}$$

where $|\boldsymbol{\mathcal{B}}|$ is the total number of the locations associated to the DBS and ω_i the weight of location i[6].

Assume that the DBS is currently hovering over location N, where $N \in \boldsymbol{\mathcal{I}}$; Algorithm 1 is described as follows:

1) Steps 1-2: Calculate the optimal altitude of the DBS with respect to each location in $\boldsymbol{\mathcal{A}}$ (i.e., the value of $h_i^*, \forall i \in \boldsymbol{\mathcal{A}}$); calculate the spectral efficiency of each location by enabling the MBS to deliver traffic (i.e., the value of $\varphi_i^m, \forall i \in \boldsymbol{\mathcal{A}}$) based on Eq. (2); initialize the user association matrix $\boldsymbol{\mathcal{X}} = \mathbf{0}$.
2) Steps 3-6: Initially, only the GUs in location N is associated to the DBS, i.e., $x_N = 1$ and $\boldsymbol{\mathcal{B}} = \{N\}$. Then, calculate the spectral efficiency of location N (i.e., the value of φ_N^d); afterwards, calculate the value of $\varphi = \sum_{i \in \boldsymbol{\mathcal{B}}} \varphi_i^d$

[6]Note that $\omega_i = 1$ in the algorithm, but the weight of a location could be proportional to the traffic demand of the location (i.e., $\omega_i = \frac{|\boldsymbol{\mathcal{B}}| \lambda_i}{\sum_{i \in \boldsymbol{\mathcal{B}}} \lambda_i}$, where λ_i is the traffic demand of location i) to further improve the throughput.

(i.e., the objective of $\boldsymbol{P2}$) and initialize the altitude of the DBS $h^d = h_N^*$, where h_N^* is the optimal altitude of the DBS with respect to location N.

3) Steps 7-15: For each iteration, update $\boldsymbol{\mathcal{X}}$ and $\boldsymbol{\mathcal{B}}$ according to Eq. (17). Based on the updated user association, calculate the optimal altitude of the DBS h^d according to Eq. (19). Meanwhile, update the spectral efficiency of each location (i.e., φ_i^d) in $\boldsymbol{\mathcal{A}}$, and then update the value of φ (i.e., the objective value of $\boldsymbol{P2}$). The iteration ends when the value of φ does not increase further as compared to the previous iteration (i.e., $\varphi^{max} \geq \varphi$).

VI. Simulations

The whole coverage area of the MBS is $1 \times 1\ km$ and the MBS is located at the center of the area, i.e., the 2D location of the MBS is $\langle 500\ m, 500\ m\rangle$. The area is further divided into 10,000 locations with each location representing a $10 \times 10\ m$ small area. The DBS is placed at the 2D location of $\langle 800\ m, 800\ m\rangle$. The mobile network operator tries to maximize the spectral efficiency of a hotspot area, which is the square area of $\langle 700 \sim 900\ m, 700 \sim 900\ m\rangle$. Other parameters are listed in Table I.

We evaluate the performance of STABLE by comparing it with other two baseline methods, i.e., Coverage maximization DBS placement (C-DBS) and Single MBS (S-MBS). In C-DBS, the optimal altitude of the DBS is selected in order to maximize the radio coverage of the DBS[7] [9]. In S-MBS, only one MBS is placed in the area and all the GUs need to download their traffic from the MBS.

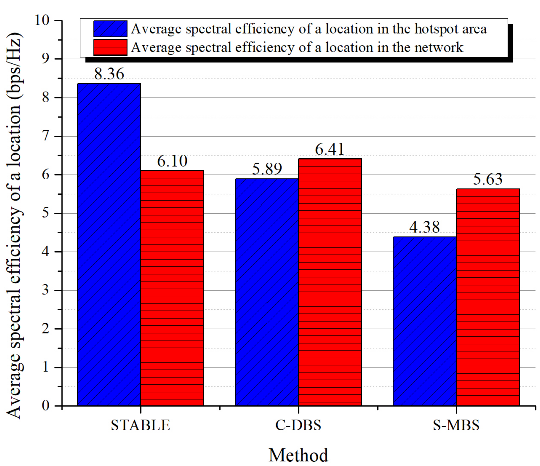


Fig. 6: Average spectral efficiency of a location.

Figure 5 shows the spectral efficiency of different locations of the network by applying three different methods. By applying STABLE, the altitude of DBS is 66.3 meters, and the spectral efficiency of the locations in the hotspot area is much higher than that achieved by C-DBS and S-MBS. On the other hand, although the spectral efficiency of the locations in the hotspot area achieved by C-DBS is lower than that achieved by STABLE, the spectral efficiency of the locations out of the hotspot area is higher than that achieved by STABLE. Figure 6 shows the average spectral efficiency among all the locations in the hotspot area as well as in the whole network. STABLE achieves the highest average spectral efficiency in the hotspot area, while C-DBS achieves the highest average spectral efficiency in the network.

[7] The radio coverage of the DBS is the sum of all the locations, whose path losses to the DBS are less than a predefined path loss threshold ξ [9]. We set up $\xi = 105\ dB$ in the simulation.

VII. Conclusion

In this paper, we have designed STABLE to jointly optimize the altitude and user association of the DBS to maximize the spectral efficiency of the hotspot area. The performance of STABLE has been demonstrated via simulations.

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