Towards Intelligent Flying Base Stations in Future Wireless Network

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***Abstract*—Recent advancements in drone technology and base station miniaturization, together with an urgent need to reduce site rental costs, have created the unique opportunity to deploy cellular networks on a platform of mobile drones. This new development is redefining the wireless networks, as drone base stations can autonomously move in space to improve coverage and capacity of the network, tremendously enhancing the quality of service (QoS) for conventional cell-edge users. In this research, we first address the possibility of deploying drone base stations and focus on the practical limitations of drones to be used in cellular networks. Then, after validating the performance of drone base stations analytically, we design autonomous mobility control algorithms for drones to improve the spectral efficiency of the floating base stations. As the optimal mobility control is NP-hard, we propose a range of practically realizable heuristics with varying complexity and performance. Simulations show that the proposed heuristics can readily achieve significant improvement in terms of spectral efficiency, packet throughput, and transmission time. A surprising outcome is that even moving the drones at minimal speeds can achieve these gains, making it possible to avoid any negative effect on drone battery lifetime.**

I. Introduction

With recent advancements in drone technology, researchers are now considering the possibility of deploying small cells base stations using drones or even plugged on dynamically flying drones. An obvious advantage of such drone base stations (DBSs) is that the operators can quickly provide cellular services in areas of urgent demand without having to pre-install any infrastructure. However, before walking down this path of DBSs and plunging into the detailed design of futuristic DBS networks, we need to acquire clear answers for the following questions:

- The viability of the business model for DBSs.
- The fundamentals on the performance of DBSs.
- The physical limitations of practical DBSs and their performance impacts.

In this research, we will explore the above questions from perspectives of market survey reports, theoretical analyses, drone simulator/hardware experiments, computer simulations of wireless communication networks based on DBSs. Afterwards, we introduce the system model and the problem statement which is addressed in the research. We focus on finding the mobility control algorithm for drones in order to improve the spectral efficiency of the drone base stations. Our proposed algorithms are described briefly in the following sections.

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A. The viability of the business model for DBSs

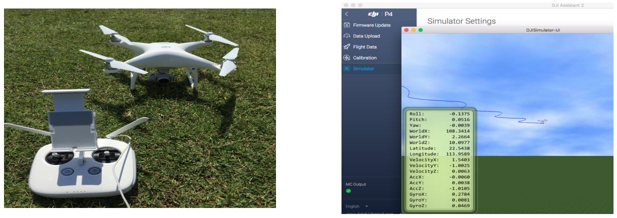
First, it is important to clarify that DBSs, which are supposed to fly at a height of cellular towers, are different from those high-altitude (20km) aerial platforms investigated by Google and Facebook to bring Internet access in emerging countries. Also, DBSs are different from those medium-altitude (200m) aerial platforms developed by European Union FP7 ABSOLUTE Project [1], which are semi-statically deployed in the sky to provide coverage for a very large area. In the proposed tutorial, we will address a new type of flying BSs, i.e., DBSs, which can autonomously move in space at low-altitude (10m) to improve coverage and capacity of the network, especially enhancing the quality of service (QoS) for conventional cell-edge users [2].

There exist several advantages of employing DBSs in commercial cellular networks including potentially no site renting cost for DBSs, potentially opportunistic communication service by the drone fleet owners, potentially easy and cheap deployment of DBSs by means of public transportation systems, and potentially simple and unified solutions of backhaul for DBSs.

However, the above advantages come at a price. In particular, we will consider short battery life for drones, air traffic management for low-altitude drones, and potential security hazards due to flying base stations.

B. The fundamentals on the performance of DBSs

To understand the fundamentals of the performance of DBSs, we will first provide a thorough survey of the existing drone technologies. Historically, drones had been used mainly in military for reconnaissance purposes, but with recent developments in light-weight battery-powered drones, many civilian applications are emerging. Use of drones to deploy small cells in areas of urgent needs is one of the most interesting applications currently being studied by many researchers [3]–[8]. The greatest advantage of this approach is that drones can be fitted with small cell base station (BS) equipment and sent to a specific target location immediately to establish emergency communication links without having to deploy any infrastructure.



(a) (b)

Fig. 1: Using Phantom drones to perfom (a) field experiments and (b) simulations

Recent studies [6]–[8] on drone small cells mainly focused on finding the single optimum location in the air for the drone to *hover* while serving the target area with a given population and traffic demand. To the best of our knowledge, the concept of dynamic repositioning drone BSs has not been adequately analysed in the literature to quantify its benefits i n t erms of coverage and capacity gain.

C. The physical limitations of practical DBSs

In order to make a good use of DBSs, we need to acknowledge the following physical limitations and regulation constraints of practical DBSs:

- DBSs cannot fly too high. Obviously, there is a flying height limitation for commercial drones. More importantly, our recent study showed that the network capacity suffers from a severer degradation as DBSs fly higher [9]. A reasonable DBS height is around 10 meters, which is also recommended by the 3GPP as the height for small cell base stations. Also, DBSs flying at a very high altitude are susceptible to wind, thus they will have to be made heavy and large, which are not safe to use in practice in case of crash.
- DBSs cannot fly too low. This is mainly due to safety reasons and regulation constraints, in order not to hit vehicles or pedestrians.
- DBSs cannot fly too fast. This is because of hardware limitations and regulation constraints. Also, previous study showed that the energy consumption of DBSs increases exponentially after a certain level of DBS speed, e.g., 10 m/s. Hence, DBSs should also not fly too fast from the view of energy consumption.
- DBSs should not fly too slow. Otherwise, the performance gain would be very small compared with terrestrial BSs.
- DBSs are not very agile. This is mainly due to hardware limitations, such that it takes some time for a DBS to make a turn, come to a full stop, etc.

As a result, we used Phantom drones [10], which are among the most popular drones, to perform both filed experiment and simulation. Subsequently, we model the drones' agility model applied in our proposed algorithms [11]. Figure 1 shows snapshots of the conducted experiments to measure the drones' limitations.

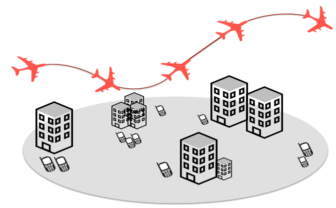


Fig. 2: Considered network architecture

II. System Model

After discussing the viability of the business model, potential achievable performance and physical limitations, we consider the system model for the proposed dynamic repositioning of drone BSs (DBSs).

The considered network area consist of multiple cells, with each cell having a pre-determined shape. In each considered cell, there is a drone that can move with a constant speed at a fixed height. Moreover, there are multiple mobile users moving around in each cell. Each drone, which may be connected to a nearby macro cell tower with a wireless back-haul link, is responsible to provide wireless communication services for the users in its cell. Figure 2 shows the considered network architecture for one cell.

When a drone is moving, the distance between the users and the drone will change, directing the drone movement to become closer to the users, improve the strength of the received signals. As a result, the drone needs to update its moving direction constantly according to the position from where users send data requests. The direction should be selected in a way to maximize the spectral efficiency of the system.

III. Problem Statement

Our objective is to maximize the spectral efficiency of the system. As a result, we need to find the best moving direction for each drone to move forward in order to obtain the highest spectral efficiency, considering the location of users and other drones. The problem can be formulated as

$$\begin{aligned} (\omega_1^*, \ldots, \omega_N^*)^t = \max \quad & \bar{\Phi}(t+\Delta t) \\ s.t \quad & |r_{u,n}(t+\Delta t) - r_{u,n}(t)| \leq v\Delta t. \end{aligned} \tag{1}$$

where ω_i^* denotes the optimal direction of the ith drone small cell at time t. The speed of drone is denoted by v, and $r_{u,n}$ denotes the distance between drone n and user u. Moreover, $\bar{\Phi}$ is the average spectral efficiency of the system where the spectral efficiency of each user can be defined by

$$\Phi_u = \log_2(1 + SINR_u). \tag{2}$$

Since the problem is NP-hard, it is impractical for large number of drones to find the optimal solution. Therefore, we propose heuristic strategies to control the mobility of drones at each time [12]. The proposed strategies are briefly described in the following.

- **Game Theory Based Strategy**: We formulated a game theory based strategy for drones to find a movement direction that maximize the spectral efficiency of the network.

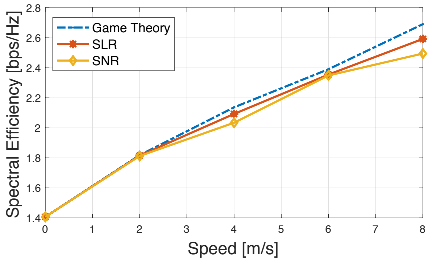


Fig. 3: Spectral Efficiency of DBSs with different speed

The set of drone base stations which are transmitting during a specific time slot are acting as the game *players*, and the set of available moving directions are considered as their *actions*. The utility function for each player is defined by the spectral efficiency of that player given the action of all players. In non-cooperative game, each player independently tries to find an action that maximizes its own utility, however its decision is influenced by the action of other players. After few iteration, players decision converges to a *Nash Equilibrium* point where no player has an incentive to deviate from it by changing its action.

- **SLR Based Strategy**: The movement of each drone effects its interference toward the active users in the neighbor cells. As a result, in this strategy each drone not only considers the received signal for its own active users, but also attempts to reduce the interference on the other active users in the neighbor cells. Each drone calculates the *SLR* (Signal to Leakage Ratio), and move towards the direction that maximizes the average SLR.
- **SNR Based Strategy**: In this model, each drone focuses only on its active users while selecting a moving direction at any movement time slot. Each drone assumes that there are no other drones in the neighborhood, and given the location of its own active users, calculates the *SNR* (Signal to Noise Ratio), and move towards the direction that maximizes the average SNR.

Figure 3 illustrates one of the preliminary result of using our proposed algorithms in a 49-cell environment where drones are moving with different speeds. There are 5 mobile users in each cell, where each cell is a square of 80m by 80m. Our proposed algorithms improve the spectral efficiency significantly compared with the hovering drones (speed of zero). Moreover, the spectral efficiency gain is increasing as speed is increasing.

IV. Conclusion and Future Work

In this research, after discussing the viability of the business model, potential achievable performance and physical limitations of drone base station, we have proposed dynamic repositioning of drone BSs as a novel method to increase the spectral efficiency of drone small cells at a low altitude. We proposed different heuristic algorithms to autonomously reposition the drones in response to user activities and mobility. Simulation results show that our proposed methods can hugely improve the spectral efficiency of the network compared with static hovering drones. Moreover, real experiments are conducted to resolve the practical limitation of drones on their power consumption and maneuverability. Applying real practical constraints on our proposed methods, it is shown that tremendous improvement for the network can be obtained even with limiting agility level for drones.

Our work opens up several directions of new research. More complex drone mobility model can be designed in order to achieve more gain. Moving with the various speed and height will bring new challenges to the research. Moreover, with advancements in camera technology and video processing, drones in the future could identify obstacles in real time. Such knowledge could be used to design more advanced dynamic repositioning algorithms to largely increase the probability of LoS communications with active users. Another direction would be to actually implement the proposed algorithms in real drones and conduct real-life experiments. Such experiments will provide insights to more practical issues and help improve the dynamic repositioning algorithms.

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References

[1] A. P. Consortium, "Aerial base stations with opportunistic links for unexpected and temporary events," http://www.absolute-project.eu, 2015, accessed: 2017-03-01.

[2] A. Fotouhi, M. Ding, and M. Hassan, "Dynamic base station repositioning to improve performance of drone small cells," in *2016 IEEE Globecom Workshops (GC Wkshps)*, Dec 2016, pp. 1–6.

[3] K. Namuduri, Y. Wan, and M. Gomathisankaran, "Mobile ad hoc networks in the sky: State of the art, opportunities, and challenges," in *Proceedings of the Second ACM MobiHoc Workshop on Airborne Networks and Communications*, ser. ANC '13. New York, NY, USA: ACM, 2013, pp. 25–28.

[4] S. Rohde and C. Wietfeld, "Interference aware positioning of aerial relays for cell overload and outage compensation," in *Vehicular Technology Conference (VTC Fall), 2012 IEEE*, Sept 2012, pp. 1–5.

[5] A. Merwaday and I. Guvenc, "UAV assisted heterogeneous networks for public safety communications," in *Wireless Communications and Networking Conference Workshops (WCNCW), 2015 IEEE*, March 2015, pp. 329–334.

[6] M. Mozaffari, W. Saad, M. Bennis, and M. Debbah, "Drone small cells in the clouds: Design, deployment and performance analysis," in *2015 IEEE Global Communications Conference (GLOBECOM)*, Dec 2015, pp. 1–6.

[7] V. Sharma, M. Bennis, and R. Kumar, "Uav-assisted heterogeneous networks for capacity enhancement," *IEEE Communications Letters*, vol. 20, no. 6, pp. 1207–1210, June 2016.

[8] X. Li, D. Guo, H. Yin, and G. Wei, "Drone-assisted public safety wireless broadband network," in *Wireless Communications and Networking Conference Workshops (WCNCW), 2015 IEEE*, March 2015, pp. 323–328.

[9] M. Ding and D. Lopez-Perez, "Please lower small cell antenna heights in 5G," *IEEE Globecom 2016*, pp. 1–6, Dec. 2016.

[10] D. Phantom, "DJI Phantom drones," http://www.dji.com/phantom, 2017, accessed: 2017-03-01.

[11] A. Fotouhi, M. Ding, and M. Hassan, "Understanding Autonomous Drone Maneuverability for Internet of Things Applications," in *2017 IEEE WoWMoM Workshops*, 2017.

[12] A. Fotouhi, M. ding, and M. hassan, "Dynamic Base Station Repositioning to Improve Spectral Efficiency of Drone Small Cells," in *2017 IEEE WoWMoM*, 2017.