# Drone-based antenna array for service time minimization in wireless networks

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## Abstract

In this paper, it investigates the effective use of multiple four-rotor drones as an aerial antenna array which offers ground users wireless service. In addition a novel framework for deploying and operating a drone based antenna array system whose elements are single-antenna drones is proposed to minimise air transport time for communicating with ground operators. The use of UAVs as data relays is a promise both for the delivery of on-demand connectivity and for the provision of public safety serves as well as for the recovery of communication infrastructure defects caused by natural disasters. Firstly, by optimising Drone Spacing within the array, the antenna array gain is optimised. In this case, the drone space optimization problem is resolved by resolving successive, disturbed problems with convex optimization using disturbance techniques. The second step consists of the optimal location of the drones at the array centre so that the service time is minimised for each ground user. The simulation results shows that, compared to a single drone that uses the same power as the array, the proposed approach can considerably reduce service times for ground users. The results also show that the spectral efficiency of the network can be improved by 78 percent while the drone array system is utilised. In comparison with a fixed array case in which the same number of drones form a fixed, uniform antenna array, the proposed method can significantly reduce ground users' time of service.

## Keyword

Unmanned Aerial Vehicle (UAV) , Drone , Wireless Communications , Optimization , service time

## Introduction

In recent years it has become an important challenge for FANET to provide access to network resources wherever and whenever possible. In mission-critical applications such as disaster recovery operations, when the transmission of data on-time is necessary, such a challenge is further agitated. There is therefore a strong requirement for wireless communications technologies which can also be used quickly to enable air-to-air and air-to-ground data communication services.[1]

The use of aerial platforms such as UAVs - known as drone - has been found to be a very promising solution to ensure that wireless communication is reliable and cost-effective.

UAVs in particular can be implemented fast and efficiently in support of mobile networks and in the form of line-of-sight communication links to enhance their quality of service. UAVs allow a number of key potential applications in wireless systems with their inherent features such as mobility, flexibility and adaptive altitude.

The efficient use of multiple drones as an aerial antenna array for ground users is investigated. In particular, a new framework is proposed for the deployment of a drone-based antenna array system with single-antenna drones, with an aim of minimising service times needed for ground users. First, by maximising drone separation within the table, the antenna array gains are maximised. [2]The drone separation optimization problem is solved in this case by solving successive, disturbed convex optimization issues using perturbation techniques.In the second step, the optimal drone location around the centre of the array is derived so that the time of service is minimised for each land user. Results from simulations show that the proposal approach can significantly reduce ground users' service time compared to one drone with the same power as the array. The results also show, that while using the drone antenna array, the network's spectral efficiency can be improved by

78%

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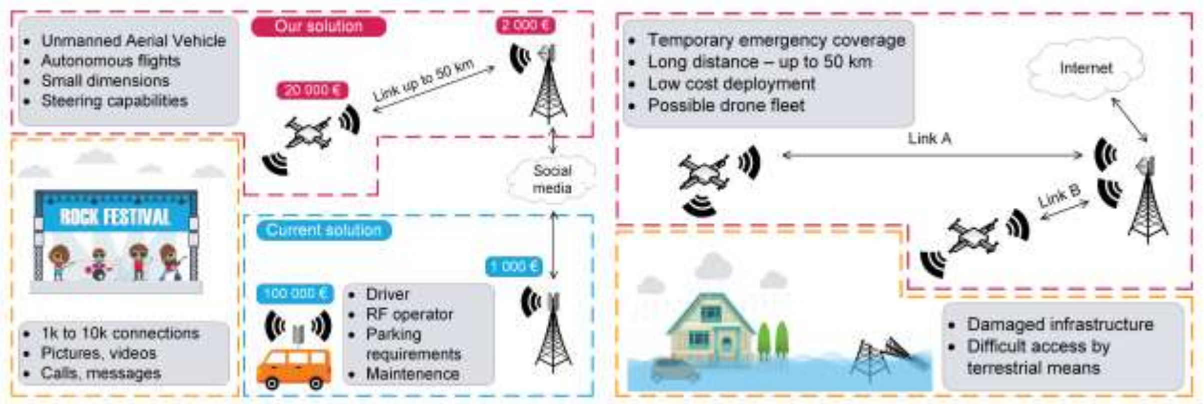
Drone

The limited flight resistance of drones is one of the key challenges in drone-based communications systems. Flying drones, of course, have a limited amount of on-board energy to be used for transmission, mobility, control, processing and payload. As a result, drones usually have a short flight time and cannot provide long and continuous wireless coverage.[3]Finding a long range, high rate and low latency communications on drone-abled wireless systems may also pose challenges as a result of the limited transmittance power of drones. A promising approach to high data rate and low service time is the use of multiple drones in an antenna array consisting of multiple individual antenna drones.



(a) Service on demand – mass event. (b) Disaster recovery.

Fig. 1 UAV base station: operating scenarios

A drone-based antenna array has the following benefits in comparison to conventional antenna array systems. First, space restrictions are not limited to the amount of antenna elements (i.e. drones). Second, by adjusting the array element distances, the gain of the drone-driven antenna array can be increased. Third, mobility and flexibility of drones allow efficient, three-dimensional (3D) mechanical beam control. A high-gain drone-based antenna array can obviously offer terrestrial users high data rate wireless services reducing service time.[4]

## UAV components

Aerial vehicles are complex hardware and software systems. Enhancing electronics allowed for increasingly available on the market the development of navigation and control systems. The main components of a UAV can be subdivided into three main groups: I the aerial platform that includes aerial airframe, navigation system, power system and payload; (ii) the GCS that enables human remote control; and (iii) the communication system that supports communication between the two other components.

Different airframes. From the left: polystyrene, plastic, aluminum, carbon fiber

Fig.2 UAV Components

The main structure of the UAV is the airframe. Its structure shall take into account the weight of power, communications and control systems, in particular, on board. In addition, the airframe must be designed adequately to withstand the forces that may occur during the flight without causing vibration and deformation. Fixed wings are made primarily of polystyrene or plastic, as shown in Fig. 2; common multirotor airframes are made of aluminium or carbohydrates (as lighter and resistant) and the number of arms depends upon the expected payload and number of motors.[5]

## System Model and General Problem Formulation

Consider a set of L wireless single antenna users within a given area. A set of M quadrantors is used as a flying access point in this area, providing ground users with downlink wireless service. The M drones form an antenna array with each element as shown in fig. 3 being a single antenna drone. We consider a linear antenna array for tractability whose elements are symmetrically excited and located around the origin of an array.The results that we will derive for the linear array case can provide a key guideline for designing more complex 2D and 3D array configurations. The 3D location of drone m ∈ M and of user i∈ L is given by $(x_i^{\mathrm{u}}, y_i^{\mathrm{u}}, z_i^{\mathrm{u}})$, and the location of

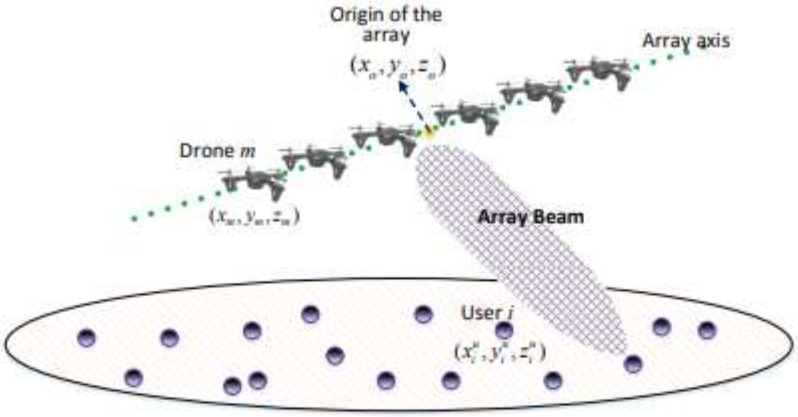


Fig. 3 Drone Based Antena Array

drone m while serving user i is $(x_{m,i}, y_{m,i}, z_{m,i})$. To avoid collisions, we assume that adjacent drones in the array are separated by at least $D_{min}$. Let $a_m$ and $\beta_m$ be the amplitude and phase of the signal (i.e. excitation) at element m in the array. Let $d_{m,i} = \sqrt{(x_{m,i} - x_o)^2 + (y_{m,i} - y_o)^2 + (z_{m,i} - z_o)^2}$ be the distance of drone m from the origin of the array whose 3D coordinate is $(x_o, y_o, z_o)$. The magnitude of the far-field radiation pattern of each element is w(θ, φ), where θ and φare the polar and azimuthal angles in the spherical coordinate.the service time, which is the time needed to serve the ground users,depends on the transmission time and the control time during which the drones must move and stabilize their locations.[6-8]

## Research Methodology

A unique classification of UAVs is difficult to achieve because it differs from one country to another. The rating depends on various parameters such as flying height, payloads, drone weight and height, airfields, endurance, speed, wings, etc (Cavoukian, 2012). These range from short and intermediate range UAVs and micro UAVs to Hale UAVs (High Altitude Long Endurance) (MAV). The functions of the drones, the strategy drones, and the combat drones are distinguished accordingly (Unmanned Combat Air Vehicle UCAV). In addition, they can also be differentiated by the type of equipment: fixated, rotary and hybrid wings (Drouot, 2013), (Arjomandi, Agostino, Mammone,Nelson, & Zhou, 2006).[9]

| | Mini and Micro UAVs | Tactical UAV | Male UAVs | HALE UAVs |
|---|---|---|---|---|
| **Altitude** | <300 m | <5000 m | 5000-15000 m | Max 20000 m |
| **Weight** | Micro → <500 g<br>Mini → <20 kg | 100-500 kg | 1800 kg | 12000 kg |
| **Application** | Civil/Commercial | Military | Military | Military |
| **Autonomy** | Micro → <30 min<br>Mini → < few hours | 10 hours | 24 hours | UAV Global Hawk: 35 hours |

Table 1. classification of UAV

## Optimal Positions of Drones In Array For Transmission Time Minimization

The optimum positions of the drones in the array can be determined by determining each user's place in this section to minimise the transmission time to the user. We consider even a number of drones without loss of generality. The same analysis still applies to a strange number of drones. Now, for M drones on the x axis of the Cartesian coordination, the table factor can be specified:

$$F(\theta,\emptyset) = \sum_{m=1}^{M} a_m e^{j(kx_{m,i}\,\sin\theta\,cos\emptyset+\beta_m)}$$

$$\overset{(a)}{=} \sum_{n=1}^{M/2} a_n\left(e^{j[kd_n \sin\theta\,cos\emptyset+\beta_n]} + e^{-j[kd_n\,\sin\theta\,cos\emptyset+\beta_n]}\right)$$

$$\overset{(b)}{=}\ 2\sum_{n=1}^{N} a_n\,cos\,(kd_n\,\sin\theta\,cos\emptyset+\beta_n)$$

Where N = M/2, and $d_n$ is the element distance n =N {1, 2,..., N} from the array centre (origin). In addition, (a) is due to the fact that the array is symmetrical in terms of origin, and (b) to the rule of Euler.[10]

Now, we can maximize the directivity of the array by optimizing $d_n$, ∀n ∈N :

$$\underset{d_n,\forall n\in N}{maximize}\ \frac{4\pi|F(\theta_{max},\emptyset_{max})|^2\omega(\theta_{max},\emptyset_{max})^2}{\int_0^{2\pi}\int_0^{\pi}|F(\theta,\emptyset)|^2\omega\,(\theta,\emptyset)^2\,sin\theta d\theta d\emptyset},$$

where ($\theta_{max}$, $\varphi_{max}$) are the polar and azimuthal angles at which the total antenna pattern $F(\theta, \varphi)w(\theta, \varphi)$ has a maximum value

## Time-Optimal Control of Drones

Here, our goal is to minimise the time spent by drones moving between the best locations as set out in Section III. We assume that the array is rotating around the centre when we move the drone based antenna array to steer the beam and to serve various users. Therefore, when moving the array, the order of the drones (i.e. indices for drones) on the array will not change.This approach makes collision prevention between drones significantly easier, since their paths are uncrossed. [11]The best rotor speeds for which the quadrotor drones can move and re-stabilize their positions in a minimum of time are obtained in this section. In the proposed Drone antenna array system, we also consider wind effects when evaluating the stability of drones.

## Dynamic Model of a Quadrotor Drone

The example of a quadrotor drone is shown in Fig. 3. This drone has four rotors which control the drone's floating and mobility. The drone can float and move horizontally or vertically, in particular by adjusting the speed of these rotors. The 3D position of the drone should be (x,y,z). Also we use($\psi r$ , $\psi p$, $\psi y$) to represent the roll, pitch, and lay angles of the drone. Rotation angles defined in terms of the body framework are roll, pitch, and lagoon. Here, the origin of a co-ordinated system body frame (represented in the $x_b$-$y_b$-$z_b$axes) is in the centre of the drone, $x_b$is in the middle of the arm of rotors 1 to 3, $y_b$is in the middle of the arm of rotors 2 to 4 and $z_b$ in the cross-product direction of $x_b$ and $y_b$.Rollower, pitch, yaw, rotation $x_b$, $y_b$, and $z_b$ are present here. Vi indicates the velocity of the rotor I to {1, 2, 3, 4} The total drive and torques leading to rolling, squatting and lowering of the rotor are linked to the speed of the rotors for a quadrotor drone:

$$\begin{pmatrix} T_{tot} \\ k_1 \\ k_2 \\ k_3 \end{pmatrix} = \begin{pmatrix} \rho_1 & \rho_1 & \rho_1 & \rho_1 \\ 0 & -l\rho_1 & 0 & l\rho_1 \\ -l\rho_1 & 0 & l\rho_1 & 0 \\ -\rho_2 & \rho_2 & -\rho_2 & \rho_2 \end{pmatrix} \begin{pmatrix} v_1^2 \\ v_2^2 \\ v_3^2 \\ v_4^2 \end{pmatrix}$$

where$T_{tot}$ is the total thrust generated by the rotors. The direction of the thrust is upward perpendicular to the rotors' plane, as we can see from Fig. 3. $\kappa_1$, $\kappa_2$, and $\kappa_3$ are the torques for roll, pitch and yaw movements. $\rho_1$ and $\rho_2$ are lift and torque coefficients, and l is the distance from each rotor to the center of the drone

## Review of Literature

Unmanned Air Vehicle Antenna Arrays This paper [4] introduces two antenna solutions for an Unmanaged Air Vehicle (UAV) in the form of a cylindrical antenna space in the UAV. The antennas work at a frequency of 2.4 GHz. The designed antennas consist of a circular range of four cylindrical-shaped elements. The basic radiating elements of each array were selected as a rectangular microstrip patch antenna and PIFA antenna.For both arrays, the radiation pattern is approximately omnidirectional. Due to their geometric dimension and required radiation pattern, the design takes into account the available space.[12] In the paper, a rectangular microstrip patch is chosen, although its radiation pattern isn't omnidirectional, in consideration of the location of the antenna and its required radiation pattern.

A recently studied topic was preventing obstacles in a 2-D environment. The Rapid Exploring Random Tree (RRT) concept was used in (Saunders, Call, Curtis, & Beard, 2005) to identify possible pathways free of obstacles in a dynamic way. The drawback of this concept is that computing time is considerable. Mixed Integer Linear Programming (MILP) was used in (Kuwata& How, June 2003) to dynamically design possible pathways to prevent obstacles. This procedure also requires greater computing ability.

Wide beam containing a large angle scanning slot antenna with phases This paper[5] discusses the design of the exponentially tapered double-layer slot antenna (DTSA), a modification of the antenna Vivaldi, which eliminates a disadvantage with regard to large sizes in the DTSA antenna. There are two back-to-back substrate arrangements, one of which is totally etched on the opposite side of the flare and the other substrate consists of strip-line feed printed and sandwiched between the two flares.Thematerial used for the substratum is RT hardoid. The solution involves three problems of matching one with the transition from line to line, the second with the transition from line to PW and the third with the transition from line to line.[13]

In addition to many of its variants, there is another well-known problem, the vehicle routing issue [Toth and Vigo, 2014]. It isn't linked directly to this work; however, further research on this topic should definitely be taken into account, as most real-life applications include multiple trucks which could consider expanding their range and shortening delivery times with one or more drones onboard.

VRP with synchronisation constraints is a specific VRP variant which can be associated with the study. A detailed review of some possibilities for these constraints is conducted in [Drexl, 2012] as it represents an increasingly interesting topic in the field. In particular, the paper aims to classify the various synchronisation types, discuss accurate and heuristic solutions to the problem and identify promising algorithmic solutions.[14]In the synchronisation restrictions designed for drone starting and rendezvous operations as intended for the problem ideators, the main influence of the VRP variant in this thesis is clearly demonstrated. The type of synchronisation in works by Murray and CHU would be classified as operation synchronisation, according to Drexl, as the drone launch would facilitate drone delivery at another location and the truck rendezvous would make it easier to use the drone for future deliveries.

## Conclusion

We proposed a new framework that could provide ground users with wireless services within minimal time for the use of a drone-enabled antenna array system. First, the UAVs were described and demonstrated their strategies and communication architectures for the drone fleet. To that end, we reduced the transmission period and the time required to modify drone sites and directions Following exposure of the various risks that influence communications in the drone networks, we aim to guarantee the transmission of a message to another drone or GCS by the receiver. In the wireless medium, several parameters play a role, such as the number of bits in the message error, message length, signal throughput, and modulation, plus the number of data to transmit. The main factors affecting the wireless medium are noise and interference. In order to guarantee a high probability of reliability, the message receipt focuses on the attempted retransmission of the proposed protocol. In our parameter values, different scenarios have been considered

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