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Initial Placement Optimization for Multi-channel UAV Networks

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Abstract. Unmanned Aerial Vehicles (UAV) can be used to deploy communication networks by acting as access points for ground users. Taking advantage of the lightness and the high maneuverability of drones, such a network can be implemented quickly and inexpensively in situations where network infrastructures are damaged or overloaded (emergency situations), or nonexistent (wild life observation). To mitigate these issues, an off-loading network based on UAVs carrying radio access points was proposed in our previous work. The goal is to temporarily provide multiple services, voice, video, data, etc., over a specific zone.

The design of the aerial network was formulated as a self-deployment method built on a Coulomb's law analogy where users and UAVs act as electrical charges. In this paper, we go beyond the proposed scheme by considering a multi-channel model taking into account the interference. We set up association and channel switching schemes that boost the overall performance of the network.

Keywords: Unmanned Aerial Vehicle (UAV) · Drone · Deployment · Channel switching · Ad-hoc network

1 Introduction

The use of flying aircraft such as unmanned aerial vehicles (UAVs), also known under the name of drones, is fast growing in a wide range of networking applications. In particular, with their ingrained attributes such as mobility, adaptive altitude and flexibility, UAVs concede several key applications in wireless systems.

Benefiting of these characteristics, future generation networks can integrate UAVs to improve the quality of service provided as well as implementing novel functionalities. Drones can be used to extend and support terrestrial networks in information dissemination, [1]. D2D (Device-to-Device) networks offer an efficient solution to alleviate terrestrial networks by offloading some traffic, but their benefits are limited as the communications are short-ranged. Drones can play a major role, as they can offer a rapid dissemination platform. As suggested in [2], UAVs can take a major part in vehicular networks as they can facilitate the information spreading by reducing the number of links needed at ground level.

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With the rapid expansion of the IoT (Internet of Things) market, the network operators have to rethink how conventional networks operate, to incorporate the massive number of IoT devices (smart-city sensors, health-care wearables, smartphones, vehicles). In poorly covered areas, IoT devices may have a hard time sending messages, as the device energy constraints limit the transmission power. In [3], UAVs could be deployed to act as base stations and to provide an energy efficient link for these kind of communications. Thanks to the line-of-sight communications and variable altitude, the signal attenuation can be reduced and the coverage area can be increased.

Natural catastrophes, apart of the devastating material destruction, can bring forth massive communication disruptions as the terrestrial communication networks can be damaged or destroyed. In such events, reliable public safety communications are needed to facilitate first responders deployment, victim search and rescue operations. The use of drone based aerial networks can be a promising solution as for the fast deployment, high coverage and flexibility [4].

All of these applications, heterogeneous as may seem, have an important common issue : the drone placement. In order to work efficiently, the UAVs have to be at the right spot at the right time.

We believe that a versatile solution needs to be dynamic (as the users could move) distributed (in order to be resilient to any loss of device or link capability) and independent of users position (as we believe that the UAV fleet cannot know the actual users position). The aim of this paper is then to propose an efficient solution. Our technique, introduced in [5], is based on a Coulomb's law analogy. Of course, in dense areas, a single UAV cannot provide network access to a large number of users. The `IEEE 802.11` standard, used in our network, offers several orthogonal channels to mitigate interference. So in this paper, we improve the coverage ratio with the use of multiple channels. For this purpose, we have to tackle two new issues: how can a drone select the channel to use? and how can a user select the drone to use as access point?

The remainder of this paper is organized as follows: Sect. 2 introduces a brief state of the art for channel allocation and optimization problems, Sect. 3 presents the system description, Sect. 4 introduces the interference management mechanism and its associated algorithms, Sect. 5 introduce the performance evaluation and Sect. 6 concludes the paper and proposes some potential extensions.

2 Related Works

Several works have already been done to take up similar issues.

In [6,7] the goal is to restore the network connectivity. Drones are used to fill the gaps serving as bridges between the disrupted infrastructures. UAVs are sent over the affected areas to interconnect terrestrial networks by relaying the messages between them. In [6], the authors use Delaunay triangulation to improve connectivity and in [7], they use a game theory approach to interconnect partitions of a network by using drones to drop relays in pre-computed spots. None of them can be used in dynamically changing networks due to the complexity needed to determine the positions of the temporary access points.

Several propositions exist in the literature as for how to optimally assign channels to reduce or eliminate the interference. Authors in [8] have studied the assignment of channels in the Multiple Radios, Multiple Channels Wireless Mesh Networks (MRMC WMN), and proposed a cross–layer mathematical formulation of joint channel assignment and multicast tree construction designed to minimize the total number of links by forming a multicast tree and thus minimize the total interference.

All these propositions cannot be used in our network as the approaches are centralized. A drone has to make decisions based on local information. In [9], the authors have proposed a distributed algorithm called Efficient Wireless Multicast (EWM) which builds a tree in which channels are assigned to the transmission for next hop in function of the used channels.

In [3], the authors efficiently collect data and recharge sensors by the aim of drones. The network is separated in multiple clusters. Unfortunately, this publication offers an overview over a static sensor network and does not look into the optimal deployment of the UAVs.

The optimal placement of UAVs in order to cover targets on-the-ground is already researched form different perspectives.

In [10, 11], the authors assume that the devices evolve in a 2D space. Therefore their problem is simplified because the coverage radius is fixed for each mobile devices. In the former article, the authors consider a mathematical model to maximize the amount of information collected based on a greedy approach and in the latter, the authors present a decentralized model for optimal positioning of sensors in order to track a target.

In [12], the authors aim to find UAV positions in order to minimize the number of drones used ensuring the surveillance of all the targets, by defining a mixed integer non-linear optimization models.

Nonetheless, the difference between the works presented above and ours is related to the constraints. Indeed, we consider that not all users have to be covered by a drone and introduce it as a constraint in our problem.

3 System Description

3.1 Scenario

The purpose of our work is to use a fleet of UAVs to set up a backbone network which provides communication means for a particular event such as a public gathering or a disaster situation when the traditional infrastructure is overloaded or wiped out. This network should be quick to deploy and inexpensive to implement, so that implicated parties (organizers, firefighters, public services) could use it rapidly. We will assume that the UAVs can communicate with each other, *eg* with the help of directional antennas. The primary objective of this work is to implement the best coverage with the minimal number of drones and with the most extended battery life possible for the UAVs.

Users position cannot be known with precision, so we will assume that we only know some specific points close to which users are more likely to be found (*eg* checkpoints).

Our main objective is to define the *initial position* of each UAV in order to maximize the number of associated users. A user can be associated to a drone if the reception power is strong enough and if the UAV can provide the required service.

3.2 Modeling Users Position

The scenario we focus on is depicted in Fig. 1. Let $\mathcal{D}$ be the set of available drones and $\mathcal{U}$ the set of users to cover. Each user $u \in \mathcal{U}$ has a fixed position at (x_u, y_u, h_u), where x_u and y_u represent the positions in $2D$ plane and h_u the altitude of the user, fixed at 0.

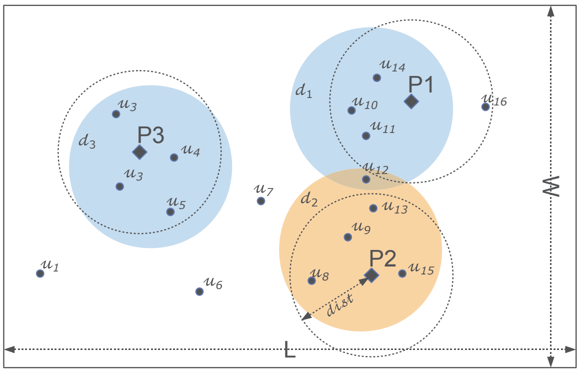

Fig. 1. Our scenario's model

Each UAV, $d \in \mathcal{D}$ is free to move into a $3D$ plane, having the coordinates (x_d, y_d, h_d). The altitude of the drone is fixed at $h_d = 100\,\text{m}$. We assume that each drone has a fixed sensing range s. A user u found in this range is then detected and can be associated to a drone. The radius of the sensing range is computed based on the UAVs altitude and its directional antenna half beam-width, in our model, $s = 50\,\text{m}$.

We consider that a drone $d \in \mathcal{D}$ covers a user $u \in \mathcal{U}$ if the distance (1) between the drone and the user is $\mathcal{L}_d^u \leq s$.

$$\mathcal{L}_d^u = \sqrt{(x_d - x_u)^2 + (y_d - y_u)^2 + (h_d - h_u)^2} \tag{1}$$

As already stated, we have already proposed an initial UAV placement strategy based on a statistical knowledge of users positions [5]. For this purpose, we have introduced a *Point of Interest* or POI as a point close to which users are more likely to be found. We have also introduced p, the probability that a user is at most at a distance d of one of the N_p POIs, named $P_1, \ldots, P_{N_p}$.

In Fig. 1, $N_p = 3$ and $p = 0.75$. Distance *dist* has been arbitrarily chosen to match the sensing range of a drone.

3.3 Modeling UAV Behavior

UAVs are supposed to get as close as possible to a maximum number of users while preserving a minimal distance to each other (in order to mitigate interference). We have thus chosen to represent their interactions with the help of a model inspired by Coulomb's law [5]. In this model, a user is described as a positive electric charge and a UAV as a negative electric charge. Drones are then attracted by users within their sensing range.

On the other hand, UAVs using the same channel have to repel one another to avoid interference. As can be seen in Fig. 2, if γ is the ratio between a user charge and a UAV charge, a low value of γ will induce a high ratio of "interfered" users (users within the range of several UAVs, that could then suffer from hidden terminal situations). Of course a high value for γ is more difficult to implement and could lead to a lower association ratio. Users are not affected by this force, being able to move freely.

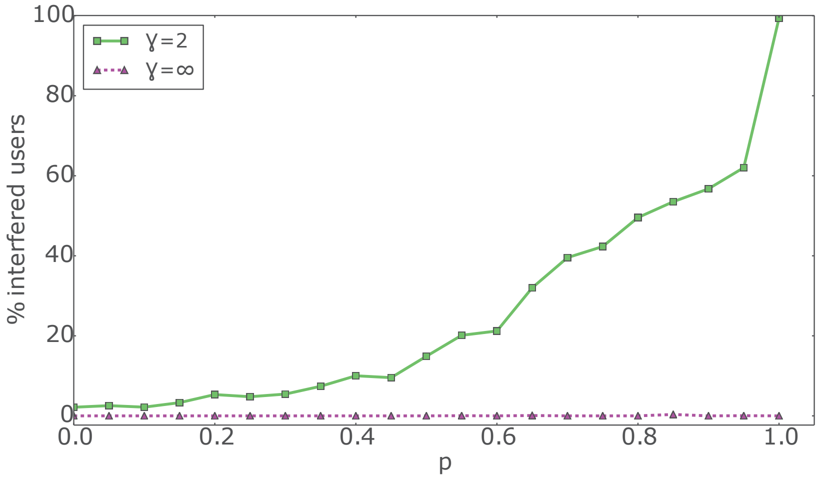

Fig. 2. Association ratio for high and low values of γ

In our simulations, UAVs are activated above POIs and aim at reaching an initial position with an optimal coverage. Such a position must be reached as soon as possible to improve battery life.

3.4 Traffic Model

In this paper, we focus on an initial UAV positioning, seeking an optimal coverage. We will not study traffic scheduling, so we will not implement a sophisticated data traffic. To bring our model closer to reality, we will however assume that each user has the same communication needs, with limited resources available on each drone. Each UAV has a fixed capacity equal to $\kappa = 50$ users. In these conditions, more UAVs are needed to cover users concentrated in the same region. A typical example, when p values are high, users will gather tightly in a small area around the POIs.

3.5 Observed Metrics

Our objective is to provide the best network access to a large number of users. We will thus measure the following parameters. The coverage ratio is the ratio of users with a high enough reception power from at least one UAV. The interfered ratio is the ratio of users covered by more than one UAV using the same channel. The associated ratio is the rate of non-interfered users, associated with a UAV. The reception power is evaluated for each user with the help of a propagation model. The battery capacity will be described with a simple model.

3.6 Path Loss Model

UAVs are situated above the users at a constant altitude $h = 100\,\mathrm{m}$, and we assume that they are in line-of-sight so, we used the Friis transmission formula [13] to calculate the received power P_R :

$$P_R = \frac{P_T G_T G_R c^2}{(4\pi R f)^2} \tag{2}$$

Equation 2 allows acquiring a magnitude of radio power sensed by a receiver located at a certain distance of a transmitter, in free space. P_T represents the transmission power, G_T represents the transmitting antenna gain, and G_R represents the receiving antenna gain. R and f symbolize the distance between transmitters and the used frequency respectively. The simulation parameters used are displayed in Table 1.

Table 1. Scenario parameters

Characteristics	Value
UAV transmission power P_{T_d}	27 dBm
User transmission power P_{T_u}	27 dBm
Transmission gain G_T	5.2 dBi
Reception gain G_R	2 dBi
Transmission frequency f	5150 Mhz
Received power threshold T_R	-65 dBm

3.7 Energy Management

A simple energy model was also integrated into the model. The purpose is to estimate the mean lifetime of a drone participating in the deployment and operation of the network. To compute the energy consumption, we took into consideration only the main equipment embarked on an UAV such as the propeller motors, the CPU (central processing unit) and the Wi-Fi antennas.

A precise model of motor consumption depends on weather conditions (temperature, atmospheric pressure, winds), propeller diameter and pitch, internal resistance and motor efficiency. We choose to use the measurements presented in [14]. The authors did an extensive study on the energy consumption in various discrete movement states of a UAV. The Wi-Fi consumption is also based on other experiments done in [15]. In this paper, the authors measured, in detail, the energy consumption for wireless nodes. The last piece of equipment took into consideration in our energy model is the CPU. We imagined that the UAVs would embark an on-board computer, like Raspberry Pi, that will run our model. In [16] the authors measured the power consumption of a Raspberry Pi based on different CPU utilization. A summary of different power consumption utilized in our simulation is given in Table 2.

Table 2. Energy consumption parameters

Characteristics	Value
One motor - hoovering	3 Amps
One motor - in move	5 Amps
One Wi-Fi antenna - idle/RX	300 mAmps
One Wi-Fi antenna - TX	400 mAmps
CPU - 50% utilization	600 mAmps
Battery capacity C_b	6200 mAh

To determine the battery lifetime we used the following equation: $T_r = \frac{C_b}{C_e}\epsilon$, where T_r is the remaining battery lifetime in hours, C_b the battery capacity in mAh, C_e the current in the drone's load. ϵ takes into account the external factors that can affect the autonomy of the battery, being equal to 0.7 in our simulations.

A UAV replacement mechanism was already studied in [17]. When a drone's battery is about to be depleted, it will send a replacement request over the control plane. A replacement UAV will come alongside the depleted drone permitting the routing algorithm to adapt the routes. When traffic is rerouted, the end-life drone will depart to the control center to recharge its batteries.

3.8 Implementation Concerns

As mentioned, we will use `IEEE 802.11` as our communication protocol between drones and between UAVs and users. To adapt our method to real life, Wi-Fi beacons and probe requests come in handy. Two different discovery approaches are proposed by the standard, passive or active scanning. In passive scanning, a station will scan all possible channels, one by one and listen to beacons. A beacon frame is sent by every access point to announce its presence.

For active scanning, a station still goes through each channel in turn, but instead of passively listening to the signals on that channel, It will send to the broadcast address a Probe Request management frame asking what network is available on that channel.

We use these two frames to implement the interactions in our network. As the access points mounted on UAVs send beacons to the broadcast address, other drones will receive them. By receiving the beacon on one of the directive antennas the UAV can approximately determine the direction of the neighboring drone. Moreover, as each UAV is equipped with GPS (Global Positioning System), we can use the beacon's timestamp to roughly determine the relative distance between drones.

Regarding the user detection, we use the probe requests that user equipment send to detect the presence in the drone's sensing range. After that, by using the information on signal and noise level, the UAV will try to determine the relative position of the user.

4 Interference Management

As presented in [5], our network performs very well without having the exact users positions. But when taking into account the interference that can be produced by neighboring drones, we notice a slight decrease in association ratio. If two or more drones are needed to cover the same area, user communications are disturbed by the nearby drone, if they use the same radio channel. As already stated, it is possible to reduce interference by increasing γ (minimal distance between drones), but in the same time, the association ratio decreases as some users will not be covered anymore.

4.1 Introducing Multi-channel

Figure 3 depicts the percentage of associated, non-interfered users for several numbers of channels. We notice that our assumptions where founded. Of course, using the same frequency on each drone, creates massive interference with more than 50% of users interfered when p is high, as UAVs are trying to cover as many users as possible.

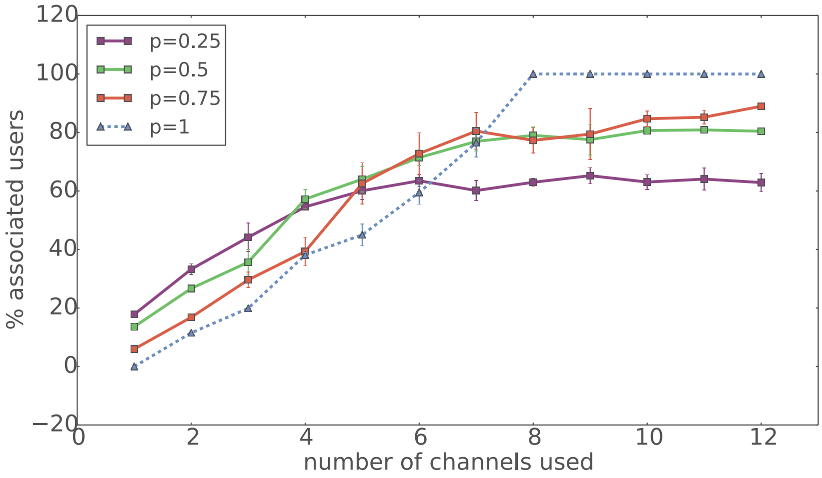

Fig. 3. User association ratio based on the number of channels

The overlapping can be managed by altering the ratio between repulsive and attraction forces. In fact, this allows us to state a trade-off between covering users and reducing interference.

4.2 Interference Management and Channel Switching

One of the improvements is related to the usage of multiple radio channels. As explained before, the system becomes interfered when multiple UAVs try to cover the same area. The main purpose is to offer an interference-free environment reducing the risk of frame collisions and reduced throughput. For this, we added a multi-channel reuse scheme to reduce interference.

Luckily, physical specifications for `IEEE 802.11` standard allow for simultaneous operation of several orthogonal (non-overlapping) channels. As an example, in the 2.4 GHz Wi-Fi band, three channels can be used concurrently. As to `IEEE 802.11a` standard, introducing the 5 GHz band, a total of twelve orthogonal channels are set forth.

By deploying antennas which allow the usage of multiple channels and affecting different non-overlapping channels when they are located in proximity, the UAVs can provide services to user on-the-ground simultaneously with minimum interference. Therefore, the association capacity of our proposed network can be increased.

Drones are collaborating, when in the immediate vicinity, to change the used channel. Each one exchanges, with its neighbors, information on the used channels. Accordingly, they adapt their own to eliminate local interference. In the beginning, every drone starts with the same Wi-Fi channel. At each iteration all UAVs will search for potential neighbors. Once found, it will choose a channel not used by another UAV in the vicinity.

As simple as it may look, it is very efficient, as it provides complete decentralized channel management. The flip-flopping between channels is mitigated as only the newest interfering drone will change the channel, bringing the neighborhood to a stable state. Besides that, as only one drone can send messages over the same Wi-Fi channel at one time, there cannot be two or more UAVs changing the channel at the same time as they have to notify the neighbors and the associated clients.

4.3 Association Strategy

As a user may be within the range of several UAVs (each one using a different channel), the question of the channel (and thus the drone) to use arises.

When a new user is covered by several UAVs (still with available capacity), then it can be associated to any of them. We have studied three different UAV association strategies:

- The simplest strategy is to use any of them, for example the first one from which a beacon is received. Let us call this the random strategy.
- The first real strategy is to implement a very simple load balancing algorithm. Users can be transferred between UAVs to reach a fair share.

- The second one is to transfer a user from a UAV to another one only if this improves the received power for this user.

If the drone capacity can be clearly stated and depends only on the number of associated users, then the random strategy is relevant. However, if the back-haul link provided by the UAV is a bottleneck, then the simple load balancer seems more appropriate. Finally, if the bottleneck is the Wi-Fi capacity, then the last one can be thought as suitable as it aims at improving transmission conditions.

Through an extensive set of simulations, we have noticed that these metrics are not really sensitive to the choice of the algorithm. As depicted in Fig. 4, the ratio of covered users is merely the same. The reception power for the users, described in Fig. 5 is not really affected neither, mainly because of the UAV altitude (in our model, the reception power depends on the distance from the UAV, and thus on its altitude). Finally, we can see in Fig. 6 that for high values of p, the random solution is more energy efficient. The reason is that it avoids some UAV movements that would follow a client transfer.

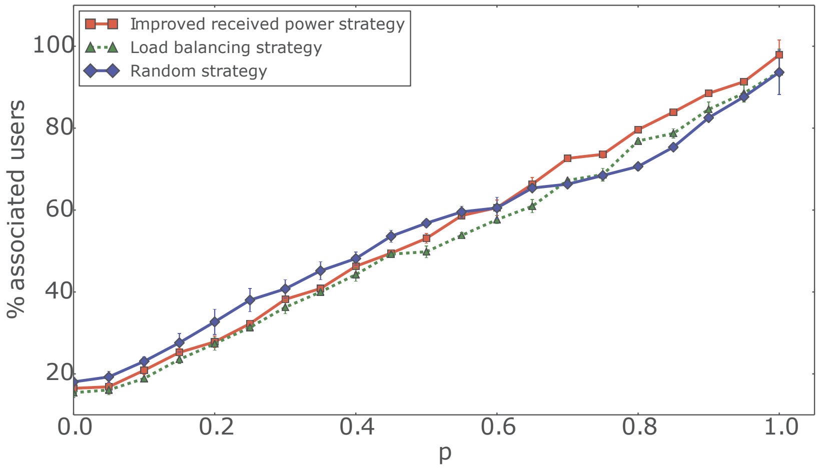

Fig. 4. Association ratio for different association strategy

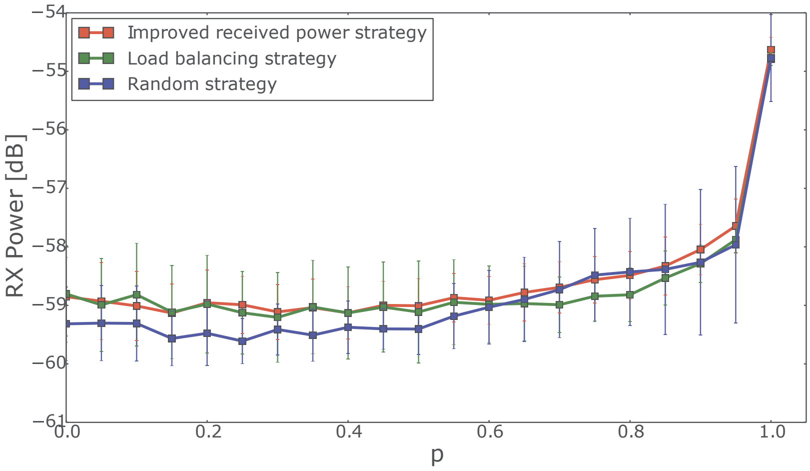

Fig. 5. Reception power for different association strategy

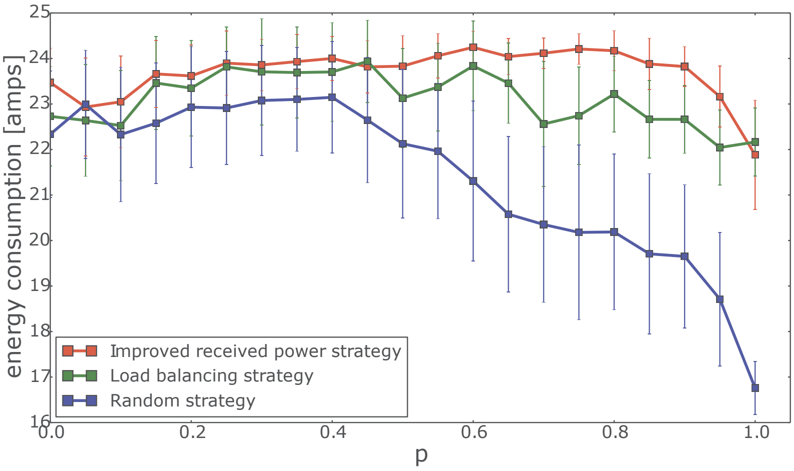

Fig. 6. Energy consumption for different association strategy

5 Simulation Performance Evaluation

In this section, we evaluate the performance of our proposed schemes with the help of a simulator that we developed.

The simulation parameters are presented in Table 3.

Table 3. Simulation parameters

Characteristics	Value
$card(u)$	500
$card(d)$	10
κ	50
$dist$	50 m
N_p	5
$(L \times W)$	1 km × 0.8 km
γ	2
h	100 m

As depicted in Fig. 7, using only one channel produces massive interference when the users are gathered around the POIs. In this cases, frame collisions and a reduced throughput can be expected. By taking into account these limitations we refined our simulator to include these new features.

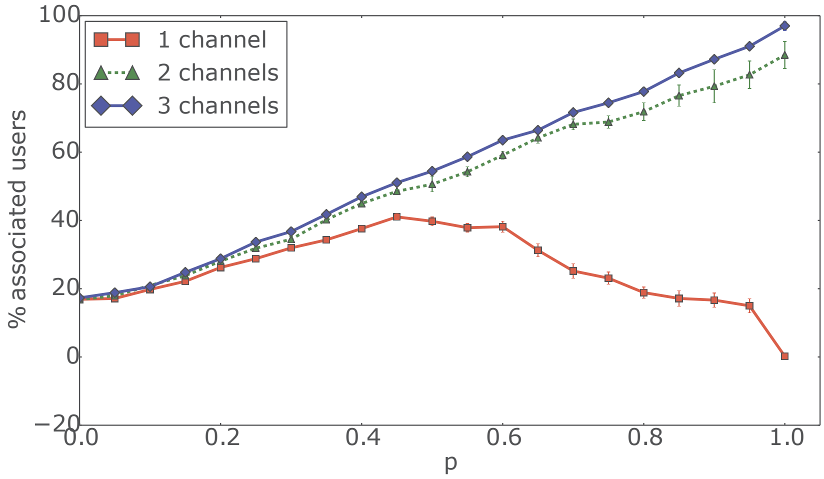

Fig. 7. User association ratio comparison when adding multiple channels

The interference that a user can sustain when multiple drones, operating on the same channel, are in its vicinity is also analyzed. To consider a user as interfered, the power received from the interfering AP (Access Point) must be higher than the receiving threshold, in our case $T_R = -65\,\text{dBm}$. All the following results are taking into account the interference. Only non-interfered users are counted as associated.

In Fig. 7 we compared the association rates for 500 users when using one, two and three channels. For low values of p, users are disseminated and the association rate is about 20%. For high values of p, because of the high user density, one channel is not enough. We see that the use of multiple channels dramatically enhances the performance for high values of p. We can also notice that for p close to 1, the number of channels needed is roughly equal to (3) where N_u is the total number of users, N_p is the total number of POIs in the network and κ is the maximum number of users that a drone can cover.

$$N_C = \frac{N_u}{N_p * \kappa} \tag{3}$$

For example, using the values from Table 3 we obtain 2 channels, $N_C = 2$. Even with this number of channels, we cannot reach a 100% user association rate for the following reasons:

- The users are not evenly distributed among POIs so that if a point of interest has 110 users, 10 of them will not be covered, with only 2 drones.
- Two POIs can be close enough so that 2 channels are not sufficient, some users being interfered by neighbor UAVs.

Taking our model to a higher scale, we analyzed the performance when a larger number of users is present. We looked into the association rates by varying the number of channels available when $n = 2000$ and have to be covered with only 40 UAVs. In Fig. 3 we depicted the association ratio when $p = 0,25$, $p = 0,5$,

$p = 0,75$ and $p = 1$. When disposing of only a small number of channels it is better when the users are more dispersed than gathered around a POI. As users are concentrated in a small area, p is high, the number of drones that can cover them without creating interference will be limited by the number of channels. When the number of channels is sufficient to cover everyone, as users are more dispersed, the number of drones needed to provide a 100% association rate grows to be inefficient to deploy that many resources to increase the association rate.

Table 4 shows the energy consumption of a drone in our network. Based on the model described before, we compared the mean battery lifetime and the mean energy consumption. We evaluate the impact of the p value and the number of channels on the energy consumption. The number of channels does not impact the battery lifetime. However, as expected, the users position has a tremendous effect on battery depletion. For $p = 1$, i.e., users are all gathered around POIs, UAVs do not have to move a lot, which saves the battery lifetime, offering approximately 16 minutes of flight time. As users are more dispersed in the given area, the drones have to travel longer distances to find them, using more power. When $p \neq 1.0$, 30% more energy is consumed by the drone decreasing the mean lifetime, as we expected. We believe that it worth adding the antennas to the UAV, battery lifetime not being drastically impacted.

Table 4. Mean energy consumption and mean battery lifetime

p	Battery lifetime	Energy consumption
$p = 1.0$	16 mn	16 amps
$p \neq 1.0$	12 mn	24 amps

Our proposed network performs remarkably well, the interference management and association schemes improve drastically the ground association rates offering better quality, not interfered transmissions and better resource allocation between users.

6 Conclusion and Future Works

We are currently working on optimizing drone placement taking into account our constraints. This optimization will allow us to observe the efficiency and performance of our self-deploying distributed network. User mobility is another critical point in our study. Being distributed and easy to implement, our solution should be efficient in a mobile scenario.

This paper proposed several novel enhancements to our network of UAVs used as access points. The network deployment is based on Coulomb's law, with users being represented as positive charges and drones as negative charges, being attracted by users. After detailing this model, we introduced two mechanisms that boost the user association ratio of the network, an interference management, and several association mechanisms. Allowing each drone taking part in the network to choose in a distributed manner the best channel to use by taking into account local interference, we point out that the non-interfered association rate of users increases remarkably. Furthermore, an analysis of energy consumption is done. Adding extra weight to drones (antennas, additional on-board computer) does not impact the energy consumption, overall battery consumption remaining reasonably acceptable, contributing to the feasibility of our proposed model in real life.

In this paper, users are evenly distributed among the POIs, they all have the same communication needs and all the UAVs have the same capacity κ. We plan to run more simulations to study the impact of these parameters.

We have shown that p is an important parameter, but its value is probably unknown in actual scenarios. We can imagine the use the UAVs discovering users position to dynamically compute an estimator of p that could be helpful to improve their behavior. Improving the performance for low values of p is also a challenge.

Finally, this work was dedicated to the initial placement of UAVs. The next step is to study how our system behaves with moving users.

References

1. Zeng, Y., Zhang, R., Lim, T.J.: Wireless communications with unmanned aerial vehicles: opportunities and challenges. IEEE Commun. Mag. **54**(5), 36–42 (2016). https://doi.org/10.1109/MCOM.2016.7470933
2. Orsino, A., et al.: Effects of heterogeneous mobility on D2D-and drone-assisted mission-critical MTC in 5G. IEEE Commun. Mag. **55**(2), 79–87 (2017). https://doi.org/10.1109/MCOM.2017.1600443CM
3. Pang, Y., Zhang, Y., Gu, Y., Pan, M., Han, Z., Li, P.: Efficient data collection for wireless rechargeable sensor clusters in harsh terrains using UAVs. In: Global Communications Conference (GLOBECOM), pp. 234–239. IEEE (2014). https://doi.org/10.1109/GLOCOM.2014.7036813
4. Merwaday, A., Guvenc, I.: UAV assisted heterogeneous networks for public safety communications. In: Wireless Communications and Networking Conference Workshops (WCNCW), pp. 329–334. IEEE (2015). https://doi.org/10.1109/WCNCW.2015.7122576
5. Rautu, D., Dhaou, R., Chaput, E.: Crowd-based positioning of UAVs as access points. In: Consumer Communications and Networking Conference (CCNC). IEEE (2018). https://doi.org/10.1109/CCNC.2018.8319279
6. Han, Z., Swindlehurst, A.L., Liu, K.R.: Optimization of manet connectivity via smart deployment/movement of unmanned air vehicles. IEEE Trans. Veh. Technol. **58**(7), 3533–3546 (2009). https://doi.org/10.1109/TVT.2009.2015953
7. Senturk, I.F., Akkaya, K., Yilmaz, S.: Relay placement for restoring connectivity in partitioned wireless sensor networks under limited information. Ad Hoc Netw. **13**, 487–503 (2014). https://doi.org/10.1016/j.adhoc.2013.09.005
8. Jahanshahi, M., Dehghan, M., Meybodi, M.R.: On channel assignment and multicast routing in multi-channel multi-radio wireless mesh networks. Int. J. Ad Hoc Ubiquit. Comput. **12**(4), 225–244 (2013). https://doi.org/10.1504/IJAHUC.2013.052866

9. Nargesi, A., Bag-Mohammadi, M., Haghighat, A.T.: Efficient multicast and channel assignment in multi-channel wireless mesh networks. In: Information and Communication Technology Convergence (ICTC), pp. 404–409. IEEE (2012). https://doi.org/10.1109/ICTC.2012.6387163
10. Wang, Q., Xu, K., Takahara, G., Hassanein, H.: Wsn04-1: deployment for information oriented sensing coverage in wireless sensor networks. In: Global Telecommunications Conference (GLOBECOM), pp. 1–5. IEEE (2006). https://doi.org/10.1109/GLOCOM.2006.482
11. Martínez, S., Bullo, F.: Optimal sensor placement and motion coordination for target tracking. Automatica **42**(4), 661–668 (2006). https://doi.org/10.1016/j.automatica.2005.12.018
12. Zorbas, D., Pugliese, L.D.P., Razafindralambo, T., Guerriero, F.: Optimal drone placement and cost-efficient target coverage. J. Netw. Comput. Appl. **75**, 16–31 (2016). https://doi.org/10.1016/j.jnca.2016.08.009
13. Friis, H.T.: A note on a simple transmission formula. Proc. IRE **34**(5), 254–256 (1946). https://doi.org/10.1109/JRPROC.1946.234568
14. Dietrich, T., Krug, S., Zimmermann, A.: An empirical study on generic multicopter energy consumption profiles. In: Systems Conference (SysCon), pp. 1–6. IEEE (2017). https://doi.org/10.1109/SYSCON.2017.7934762
15. Zhao, Z., Mao, Y., Shi, G., Dou, Z., Shu, Y.: Energy-efficient data gathering in high-voltage transmission line monitoring system. In: Mobile Ad-hoc and Sensor Networks (MSN), pp. 45–51. IEEE (2011). https://doi.org/10.1109/MSN.2011.34
16. Kaup, F., Gottschling, P., Hausheer, D.: Powerpi: measuring and modeling the power consumption of the raspberry pi. In: Local Computer Networks (LCN), pp. 236–243. IEEE (2014). https://doi.org/10.1109/LCN.2014.6925777
17. Rautu, D., Dhaou, R., Chaput, E.: Maintaining a permanent connectivity between nodes of an air-to-ground communication network. In: Wireless Communications and Mobile Computing Conference (IWCMC), pp. 681–686. IEEE (2017). https://doi.org/10.1109/IWCMC.2017.7986367