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PAPERS

Multi-UAV integrated HetNet for maximum coverage in disaster management

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This article presents a practical method for the 3D placement of a group of HetNet of unmanned aerial vehicles (UAV)-mounted base station (mBS) to offer maximum wireless connectivity and coverage for terrestrial users in a particular region. There are two ways to solve this issue. First, the ideal flying height for each UAV is determined based on the transmit power of the UAV, which offers the maximum ground coverage radius. Depending on their ideal flying altitudes and transmitting power, UAVs are divided into several categories. Given a collection of UAVs, the proposed approach identifies an optimum subset of the available UAVs and places them optimally in 3D to offer maximum coverage of the network for a particular area on the terrestrial ground while using the least amount of power. The results of the simulations show that the suggested approach is effective, and they also give important visions about the behavior of the HetNet supported UAVmBS cell subnetworks.

K e y w o r d s: multi-UAVs, HetNet UAVmBS, disaster management, disaster recovery, maximum-coverage

1 Introduction

Unmanned aerial vehicles (UAVs), including balloons and drones, have been used more often in recent years to increase the capacity of terrestrial networks and to improve wireless coverage [1]. Thanks to advancements in wireless networking technology, wireless transceivers mounted on UAVs will allow them to interact with both ground stations and other UAVs in the future. UAV-aided wireless communications have gained a lot of research attention because of their flexibility of deployment [2]. Consequently, UAVs can act as Arial base stations (BSs) to build an ad-hoc network and offer wireless on-demand connectivity and coverage to help overburdened cellular networks in congested regions or offer wireless communication in distant areas where infrastructure is lacking [3]. It is especially helpful when the terrestrial network needs assistance or is unavailable in providing the desired coverage and capacity. During emergency management and disaster recovery exercise, Verizon has established aerial long-term evolution (LTE) facility to deliver 4G-LTE facilities in "coverage deprived regions" [4]. Aerial wireless networks such as Google's project loon [5] and Facebook's project Aquila [6] use UAV technology to deliver distant regions and rural areas with ubiquitous internet connectivity of speed of 4G-LTE. As a result, UAVs have been used in a variety of applications, including wireless powered communication networks [7], mobile edge computing [8], secure communications [9], and emergency communications [10].

UAVs become a better probability of creating line-of-sight (LOS) connections for communicating with the terrestrial nodes because of their intrinsic characteristics in-cluding higher altitudes, mobility, and flexibility [11]. The communication between ground-to-ground nodes might suffer from poor link quality due to obstructions (like large human-made buildings/structures and hills) or dispersed nodes. Multi-UAV integrated HetNet is especially beneficial in these cases. Because of these benefits, wireless providers like AT&T are increasingly turning to UAVs to improve wireless coverage in crowded areas like stadiums, large events, and natural disasters [12] when the terrestrial network is overloaded and requires additional help to sustain its level of service.

When using UAVs for wireless networking, there are several unique technological problems in comparison to traditional terrestrial networks. Among the main characteristics that make UAV-based communication apart from conventional wireless networks are the following: a) coverage performance is dependent on elevation angle and LoS propagation; b) channels are highly dynamic because both the ground operators and the aerial base station are mobile, and c) the rotation and structural design of the UAV cause airframe shadowing [13]. In UAV communication, the key design issues are energy efficiency, 3D deployment of the UAVs, cell association, and allocation of resources. The optimization in UAV placement/deployment, numerous applications in diverse fields [14, 15], and transmission models (Air-to-ground (A2G), Ground-to-Air (G2A), Air-to-Air (A2A)) [16–18], have all been studied recently as design challenges in UAV communications research as well. The UAV deployment issue is critical because it has a direct impact on the over-

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all energy consumption, coverage area, and the amount of interference caused by the UAVmBSs.

1.1 Motivation, contribution and scope of the paper

In the incident of unforeseen or transient events, terrestrial base stations may not be able to fully meet the resilience and agility necessities of upcoming cellular networks. Drone-cells, which are low-altitude unmanned aerial vehicles equipped with base stations, are a possible approach for assisting the cellular network. Drone cells give a speedy deployment option as airborne base stations, but efficient deployment becomes one of the major challenges. Aside from the drone cell's horizontal and vertical dimension mobility, the discrepancies between the terrestrial and air-to-ground channels lead drone-cell installation to differ from those of terrestrial base stations. In this article, the primary motivation is to examine the successful deployment of a HetNet of aerial quasi-static UAVmBSs with different coverage radii and transmit power to maximize the area of coverage while considering the overall energy consumption of the UAVs. Only a few of the researchers [15, 17] consider HetNet into account to maximize the area of coverage. Also, in the previous research articles, HetNet is used for other applications like in dense urban cities for providing communication services rather than for disaster management systems. Here in this article, we consider HetNet for disaster management systems by taking the different altitudes of UAV and its operating frequency based on the different technology like Bluetooth, Wi-Fi, WiMAX, 4G-LTE, *etc.* For densely populated areas and more coverage radius, we consider WiMAX and 4G-LTE at a higher altitude of UAV and for minimum coverage radius we can take Bluetooth and Wi-Fi mounted UAV at a low altitude of UAV. The novelty of this article is to take HetNet so that we can cover a larger geographical area and provide communication services to every ground user in case of urban disaster. The scope of this article is to efficiently deploy the UAVs as it directly affects the coverage area, total transmission power, and interference due to other UAVs in the vicinity. The main contribution of this article is as follows:

- It proposed a multi-UAV integrated HetNet model for disaster management.
- It presents a system model for HetNet based on different transmission power and different coverage radius.
- Moreover, it finds out the optimum flying height for each UAV in a disaster for maximum coverage and capacity.
- Finally, it describes the simulation setup and discusses its results.

2 Related work

The A2G channel modeling is the prime focus of the vast majority of current UAV communications research. For example, a statistical generic A2G propagation model for low altitude platform (LAP) is developed [16] where the likelihood of LoS communication link is calculated as a function of elevation. It fails to carry out physical verification of the design by deploying a genuine LAP transmitter with a ground test drive configuration, which will allow the measurement of received power in different places and under diverse urban settings. The research in [17] looks at how pathloss and shadowing influence UAV communications in densely populated disaster situations. The properties of the A2G channel are dependent on the altitude of the UAVmBS, as mentioned in [18] because of shadowing and pathloss. It does not consider the obstacles present inside buildings in their pathloss model. The authors in [19] provide an in-depth look at the various A2G propagation models that are currently available. The authors in [20] offer a logical technique for optimizing the height of a single-UAV for full coverage to the terrestrial user to meet the UAV deployment problem. To maximize the number of ground users that can be covered, the authors in [21] investigate a UAV-enabled small cell deployment optimization issue with a terrestrial wireless network present. The authors in [22] determine the ideal height of a single UAVmBS using a Rician fading channel. Even though they provide light on UAV communications, the research reported thus far is restricted to just a single UAV. It is a very difficult task to deploy multi-UAVs at once because the change of distance between the UAVmBS as well as their relative locations will affect the performance of the total coverage. In addition, extra interference avoidance techniques are required because of the occurrence of interference between the various UAVmBS received signals.

A new deployment method for UAV rechargeable energy efficiency is presented in [23] to enable unified connection in metropolitan areas. Two UAVmBSs were placed at a constant height and the impact of the intercell intervention on the entire coverage was studied in [24]. The work in [25] investigated the usage of several UAVs as wireless relays to let ground sensor nodes communicate with one another. Though, the authors do not take into account the usage of UAVs as mounted Base Stations it only considers UAVs as a relay node. The authors in [26] presented a technique for placing homogeneous UAVmBS in temporary wireless networks that allows the overlapping of coverage regions by various UAVs, demanding the use of intercell interference cooperation (ICIC). Assuming the UAVs operate in the same frequency band and fly at the same height, the research in [27] presents an outline for doing a throughput study in a wireless multi-UAV network. The authors then developed a power-control strategy for reducing the impact of ground-user interference. It is difficult to integrate the response of the joint optimization of power control and user scheduling into the paradigm of the block coordinate descent method to ensure convergence, and more research is needed. The horizontal 2D locations of the UAVs are adjusted in the case of a constant flight height for UAVs in [28] to decrease the number of UAVmBSs necessary to cover certain terrain users. In [29], more analysis is made of the optimum placing of symmetrical multi-UAVs, assuming the same altitude and transmission power.

Some study has been done on the UAV deployment plan to cover vast or dispersed users on the ground [28, 30–32]. The authors in [30] used the K-means algorithm to arrange numerous UAVs to cover scattered users on the ground in an LoS-dominated UAV ground user channel, and stationary ground BS assisted the uncovered users on the ground. In [31], an optimal deployment strategy for a single UAV was suggested to increase the coverage of users on the ground while using the least amount of transmit power. The authors in [28] presented the spiral placement algorithm, which involves installing UAVs progressively, to assist users on the ground with a minimum number of UAVs, starting from the periphery of the area boundary and spiraling inside until all users on the ground are covered. The authors in [2] presented an integrated paradigm for studying UAV communications based on non-orthogonal multiple access (NOMA). To increase the functioning of the NOMA-UAV networks, the authors in [32] discovered the ideal deployment of UAVs. To optimize the average coverage and capacity of UAVs, we investigate a coverage method of multi-UAV that can service all the SAR members in this article. This article assures that all SARs are assisted by the installed UAVs, unlike reference [30], which allows some users on the ground to be uncovered by UAVs. The authors in the article [31] and [32] do not consider the deployment of multi-UAVs to cover large or dispersed users on the ground that cannot be governed by a single UAV. Although UAVs cover all users on the ground in [28], the researchers do not examine the UAV placement in terms of UAV's capacity.

To safeguard data against intrusions, this study [33] proposed a UAV-aided HetNet model which incorporates the unique functional encryption (FE) method for the dense metropolitan region. The UAV serves as a relay node for user equipment (UEs) that are communicating with macro-based stations in a non-line-of-sight of communication. The FE approach is used in the network in two phases to secure data transfer between UAV, UE, and macro-based stations: the first phase is between UE and macro-based stations, and the second phase is between macro-based stations and UE via UAV. Throughout implementation, the Dolev-Yao attack paradigm is examined, in which intruders might change or intercept UE data. In paper [34], the authors concentrate on the clustering strategy for users within the UAV coverage region during catastrophe recovery. Cluster heads (CHs) are chosen to detect UAVs' wireless coverage in disaster-restricted locations and provide emergency coverage services. When a UAV establishes a communications link that is visible to ground users, its power usage drops. Following that, CHs displays a communication link with device-to-device (D2D) communication as well as cluster members (CMs) with the UAV decentralized control. To ensure its usefulness in post-disaster communications, the performance of the likelihood of line-of-sight (LoS) and received signals is examined at varied UAV heights.

This study is mainly aimed at developing an effective approach for the placement of heterogeneous UAVs to maximize network coverage in a particular region of interest. We first acquire the properties of the air-to-ground (A2G) channel to create the suggested method. Then, we identify an optimum flying height for each UAV as per their environmental drivers and transmission power, to exploit the greatest potential of UAVs. Moreover, we compute the lowest number of UAVmBSs and its optimum location to offer a maximum area of coverage while minimizing the resources accessible (overall UAVmBS transmission power) as well as preventing intercell interference to decrease the overhead of the network.

3 Multi-UAV integrated HetNet proposed model

A huge number of non-active and active users make up the UAV-supported HetNet model. In case of an urban disaster, highly demanding data produces high levels of traffic for active users in the metropolitan region. UAV helps to manage this data traffic effectively as an intermediary node. In addition, the UAV acting as relay nodes offers comprehensive coverage with nearly congestion-free pathways for all receiver users for data packages. Depending on the different applications of users, UAVs may be placed at the ideal height of a few km or 100 m from the base station. From the communication perspective, to manage control links the UAVs employ part of the S-band, and to communicate with User Equipment (UE) and Ground Station (GS) it uses part C-band for the payload.

Deployment of low-power nodes such as picocells, femtocells, and relay nodes within macro cell coverage is seen as a cost-effective way to increase system capacity and to equip wireless WANs with the ability to keep up with the increasing demand for data capacity. These new types of deployments are commonly referred to as heterogeneous networks and are currently receiving significant attention in the industry. A HetNet is an architecture with a mobile cell densifying mechanism that covers many parts of the mobile cell networks, for instance, if a macrocell covers a femtocell and piconet, it forms a three-stage HetNet [35]. The small cell alliance characterizes small cells as "a generic name for the operator's low power access nodes." The small cell is otherwise called a low-power cell which is regulated by the providers of mobile networks. It is known as the gap between Wi-Fi access points and small cells.

The small cell alliance also defines small cells based on the coverage and application into four different areas, the minimum coverage is obtained by using femtocell in the home, and for business purposes, a picocell is used, whereas microcells and macrocell are used for rural mobile facilities and public hubs for maximum coverage [36]. All the small cells discovered by the small cell alliance are not nevertheless considered as mobile nodes. The characteristics of a multi-UAV integrated HetNet are dynamic

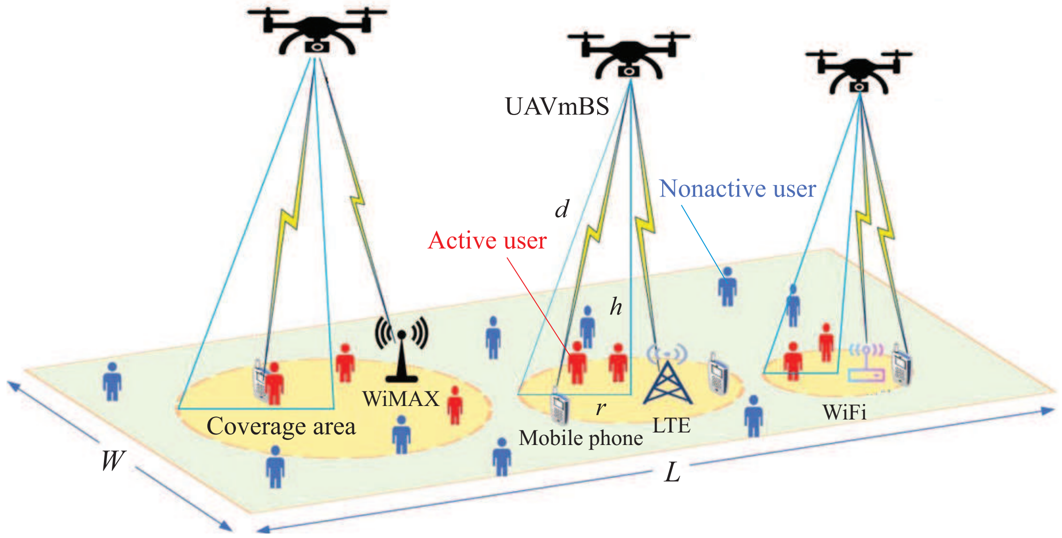

Fig. 1. Proposed model based on the multi-UAV integrated HetNet for disaster management

placement/operation, dense placement of cells with decreased cell size, advanced public safety multi-tier LTE network, self-organization, and flexible backhauls [37]. Figure 1 presents the proposed model based on multi-UAV integrated HetNet for disaster management.

3.1 System model for HetNet UAVS

Let a HetNet of multi-UAVs which are of different categories based on their transmission power. Letting $\mathcal{U} = \{U_i\}_{i=1}^{N}$ represents the set of N UAVs where $P_i^{\rm t}$ is the corresponding transmission power of U_i UAV. Consider a geographical area of 2D for urban disaster where UAVs are placed in such a way that maximum area of coverage is obtained. Depending upon the shape and size of the geographical area that needs to be covered accordingly the number and type of UAVs are deployed. In this case, we consider the disaster area is of the rectangular shape of size $L \times W$ where L is the length and W is the width. In this article, we deploy a quadrotor low altitude platform (LAP) UAVs that are quasi-stationary. Even though UAVs are quasi-stationary, they can attain different heights based on their transmission power to achieve maximum coverage range.

To examine the UAV's wireless coverage, we first look at the A2G propagation method. Because it has a greater possibility of a LoS connection, the A2G propagation model differs significantly from the terrestrial propagation model. The radio signal coming from the LAP UAV mounted Base Station (LAP-UAVmBS) as mentioned in [16] and [20], propagates to its target in one of two ways. One way is to receive an LoS signal whereas the other way is to receive a robust non-LoS (NLOS) owing to diffractions and reflections. Those ways may be taken independently with a varying probability of occurrence based on environmental characteristics such as elevation angle, as well as building height and density. The radio signals transmitted by the LAP UAVmBS travel across free space until they reach ground receivers. The free space pathloss (FSPL) is the most significant attenuation that a LAP signal experiences and are given by

$$P_{\rm FS} = 20 \log \frac{4\pi f_c d}{c}, \tag{1}$$

where c is the speed of light and f_c is the carrier frequency. Moreover, as illustrated in Fig. 1, $d = \sqrt{h^2 + r^2}$ is the distance between UAVmBS and the user positioned in a 2D plane at the ground at radial distance r from the UAVmBS.

Besides FSPL, the radio signals suffer extra losses generated by LAP UAVmBS due to scattering and shadowing induced by the environment's barriers. As a result, for the A2G channel, the overall mean pathloss-model is

$$P_{\rm L} = P_{\rm FS} + \eta_\xi, \tag{2}$$

where η_ξ denotes extra pathloss due to scattering and shadowing, and ξ denotes the propagation group such that $\eta_\xi \in \eta_{\rm LoS}, \eta_{\rm NLoS}$. Each propagation group has a unique probability that is determined by the environment. Extra pathloss, has two values: LoS and NLoS, with probabilities $P_{\rm LoS}$ and ($P_{\rm NLoS} = 1 - P_{\rm LoS}$), respectively. The probability of getting LoS signal from LAP UAVmBS for a user positioned on the ground is determined by the height h_i of the UAVmBS and its horizontal distance to the user is given by ($r_i = \sqrt{(X - x_i)^2 - (Y - y_i)^2}$), is the position of the UAVmBS at the 2D surface. The LoS probability is

$$P_{\rm LoS}(h_i, r_i) = \Big[1 + \alpha \exp(-\beta\big(\arctan \frac{h_i}{r_i} - \alpha)\Big]^{-1}, \tag{3}$$

where α and β are constant values that are dependent on the environment. We take the spatial assumption of pathloss for LoS and NLoS connections into account because we can't decide whether the connection is LoS or NLoS in advance.

$$\overline{P}_{\mathrm{L}} = P_{\mathrm{FS}} + \eta_{\mathrm{LoS}} P_{\mathrm{LoS}} + \eta_{\mathrm{NLoS}} P_{\mathrm{NLoS}} \,. \tag{4}$$

By putting values of FSPL and P_{LoS} into (4) we get,

$$\overline{P}_{\mathrm{L}} = 20 \log d_i + \frac{A}{1 + \alpha \exp(-\beta(\theta - \alpha))} + B, \tag{5}$$

where $d_i = \sqrt{h_i^2 + r_i^2}$, $A = \eta_{\mathrm{LoS}} - \eta_{\mathrm{NLoS}}$, and $B = \eta_{\mathrm{NLoS}} + 20 \log \frac{4\pi f_c}{c}$.

3.2 Optimum flying height for each UAV in disaster

Unlike traditional terrestrial base stations, the UAVmBS's coverage radius is unknown prior and is dependent on their height. As a result, to fully exploit the UAV's potential, we determine the best flight height for each UAV that provides the maximum ground coverage radius. We find its optimum flight height h_i, which increases the size of the coverage region, for UAVmBS with U_i and P_i^{t} its transmission power. The service threshold is defined as the lowest allowed received signal power for successful transmission. If the received power of the signal exceeds a given threshold value ϵ then the whole area is covered.

Here is no intercell intervention between the UAVmBSs because the UAVmBS's coverage regions do not intersect. As a result, determining the service threshold using the signal-to-noise (SNR) criteria is equal to using the signal-to-noise-plus-interference (SINR) condition. After determining the pathloss as predicted in (5), the received power signal at a terrestrial user placed radially r_i from the UAV's ground picture is given by

$$P^{\mathrm{r}}(dB) = P_i^{\mathrm{t}} - \overline{P}_{\mathrm{L}} \,. \tag{6}$$

Here in this case the received power should be greater than ϵ, *ie*, $P^{\mathrm{r}} \geq \epsilon$. So, the resultant equation is

$$\overline{P}_{\mathrm{L}} \leq P_i^t - \epsilon \,. \tag{7}$$

From (7), the wireless coverage of a given geographical area is solely determined by the average pathloss $\overline{P}_{\mathrm{L}}$ encountered at that location for a particular transmit power P_i^{t}. The pathloss $\overline{P}_{\mathrm{L}}$ in (5), on the other hand, is a measure of the UAV's height h_i and the horizontal distance r_i from the ground receiver. As a result, all ground receivers at the r_i radial distance incurs the same pathloss for a fixed floating height h_i. It's the same as saying the locus of the spots on the two-dimensional region has the identical pathloss in the circle-centered on the UAV's terrestrial image. A circular disk is thus the area of coverage for UAVmBS.

The radial distance where the power signal received by the receiver on the ground surpasses the threshold is defined as the radius of coverage for a UAVmBS U_i with P_i^t as its transmission power and is given as

$$R_i \triangleq r_i | \overline{P}_{\mathrm{L}} = P_i^t - \epsilon \,, \tag{8}$$

where R_i denotes the radius of coverage of UAVmBS U_i. By putting (5) in (8) the equation turns out to be

$$20 \log d_i + \frac{A}{1 + \alpha \exp\left[-\beta(\arctan \frac{h_i}{R_i} - \alpha)\right]} + B + \epsilon - P_i^{\mathrm{t}} = 0 \,, \tag{9}$$

$$P_i^{\mathrm{t}} = 20 \log d_i + \frac{A}{1 + \alpha \exp\left[-\beta(\arctan \frac{h_i}{R_i} - \alpha)\right]} + B + \epsilon \,, \tag{10}$$

here $d_i = \sqrt{h_i^2 + R_i^2}$, and R_i is an implied component of h_i, as shown in (9). This equation is, however, a unimodal component with the only one-stationary point that results in maximum coverage radial distance. Let h_i^* be the optimum flight height that yields the maximum radius of coverage. Now, calculating h_i by carrying out the partial derivative of (9) as follows:

$$\frac{\partial R_i}{\partial h_i} = 0 \,. \tag{11}$$

Now the resultant equation can be written as

$$\frac{h_i}{R_i} + \frac{9 \ln(10) \alpha \beta A \exp\left[-\beta(\arctan \frac{h_i}{R_i} - \alpha)\right]}{\pi\left(\alpha \exp\left[-\beta(\arctan \frac{h_i}{R_i} - \alpha)\right] + 1\right)^2} = 0 \,. \tag{12}$$

The ideal flight height h_i^* and related radius of coverage R_i of the UAVmBS $U_i \in \mathcal{U}$ as a function of P_i^{t} its transmission power and environmental factors are obtained by mathematically evaluating the equations (9) and (12). We allocate a profile P for every UAVmBS as a combination of its coverage radius, height, and transmission power after determining the maximum coverage radii and optimal flight height for the accessible UAVs in the repository:

$$\mathbf{P}_i \triangleq (R_i, h_i, P_i^{\mathrm{t}}) \,, \quad i = 1, \ldots, N \,. \tag{13}$$

4 Simulation setup

We analyze for simulation of UAVmBS communications in an urban disaster by taking carrier frequency *ie*, $f_c = 2$ GHz, with environmental parameters as $\eta_{\mathrm{LoS}} = 1$ dB, $\eta_{\mathrm{NLoS}} = 20$ dB, $\alpha = 9.61$, $\beta = 0.16$. For a successful transmission, we suppose the minimum permitted received power signal is $\epsilon = -60$ dBm. In addition, also we analyze a collection of sixteen UAVs in which each kind has four alike UAVmBSs with transmitting power of 50 dBm, 43 dBm, 39 dBm, and 35 dBm. The aim is to deliver wireless coverage for a geographic area of $10\,\mathrm{km}^2$. Table 2 shows a summary of the simulation parameters.

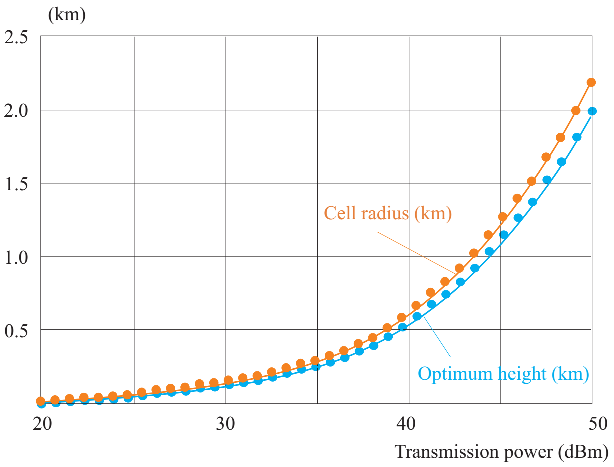

Fig. 2. UAVmBS with different transmission power for optimum flight height and corresponding coverage radius for urban disaster

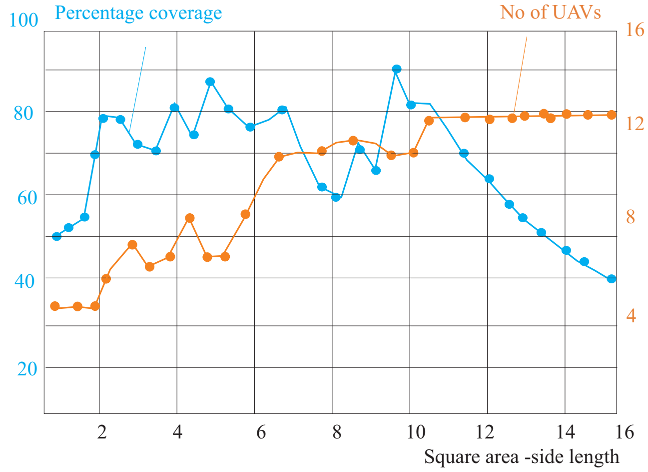

Fig. 3. Number of UAVmBS deployed and the percentage coverage for various disaster sizes

Table 1. Parameters for simulation

Parameter	Value	Parameter	Value
η_{LoS}	1 dB	α	9.61
η_{NLoS}	20 dB	β	0.16
L	10 km	W	10 km
f_c	2 GHz	$\in$	-60 dBm
N	16	ξ	0.05
P^t = 50 dBm, 43 dBm, 39 dBm, 35 dBm			

5 Results and discussions

By equations (9) and (12) together, Fig. 2 depicts the maximum radius of coverage and the best flight height as a function of transmission power. As shown in Fig. 2, raising the transmission power increases both the maximum radius of coverage and the ideal flight altitude at the same rate. It has been discovered that for larger values of transmission power P^{t}, the ideal altitude may surpass the physical restrictions for LAP-UAV systems, necessitating the imposition of a con-straint on h in actual situations. In addition, we can acquire the profile of the UAVmBSs using Fig. 3 and (13). We have four separate UAVmBS profiles because there are four distinct forms of UAVmBSs in the collection: $P1 = (35\,\mathrm{dBm},\ 0.35\,\mathrm{km},\ 0.41\,\mathrm{km})$, $P2 = (39\,\mathrm{dBm},\ 0.58\,\mathrm{km},\ 0.65\,\mathrm{km})$, $P3 = (43\,\mathrm{dBm},\ 0.92\,\mathrm{km},\ 1.01\,\mathrm{km})$, and $P4 = (50\,\mathrm{dBm},\ 2.05\,\mathrm{km},\ 2.39\,\mathrm{km})$, where the first one is their transmission power, second is the optimum flight height, and third is the radius of coverage.

Figure 3 depicts the percentage of coverage and the number of UAVmBS deployed for a square region as a function of geographical area. Here, we can see that number of UAVmBS deployed is not growing monotonically with the disaster area's size. This is owing to the UAV's heterogeneity and variance in coverage radius. Surprisingly, the greatest coverage percentage for a $10\,(\mathrm{km}^2)$ region is obtained utilizing only thirteen UAVmBSs, depending on the accessible UAVmBSs in the repository. When the area's side length reaches $11\,(\mathrm{km})$, all sixteen UAVmBSs can be installed without interfering with each other.

In articles [15], and [17], the authors take into consideration HetNet of UAVs but only compare its performance based on different operating frequencies and different UAV's altitude and fail to carry out its performance based on different UAVs transmission power based on its cell radius and its coverage percentage for a given number of UAVs. Hence, this article will help to optimally deploy HetNet of multi-UAVs to successfully cover the maximum geographical area and also increase its capacity to serve the maximum number of ground users.

6 Conclusions and future directions

This article established a strategy for allocating resources and optimizing the 3D deployment of a group of heterogeneous UAVmBSs to offer wireless coverage for terrestrial users in a given disaster region. Firstly, we calculated the UAVmBS's ideal flight height as a function of environmental variables and transmission power. Secondly, to give the maximum coverage to the wireless network for the existing UAVmBSs, the authors devised an optimized solution that identifies the best allocation of resource techniques as well as the UAV's position. In addition, the HetNet of multi-UAVmBSs increases the capacity and coverage of the wireless network as it covers small cells as well due to the heterogeneity of the UAVmBS. Research work can be done in the future, on how to effectively establish a UAV-to-UAV collaboration based on the heterogeneous network for disaster risk management across a vast region. Also, we will work on the optimization model by taking energy consumption models and service time into account.

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