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3-D Placement Schemes of Multiple UAVs in NFP-based Wireless Networks

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***Abstract*—In this paper, we propose two placement strategies of multiple unmanned aerial vehicles (UAVs) in network flying platform (NFP)-based wireless networks. The first strategy is based on a proposed distributed placement algorithm (DPA) that can be executed by the collaboration of the users and a high altitude controlling NFP (mother UAV). The second strategy uses a proposed centric placement algorithm (CPA) at the mother UAV to define the number and optimal placement of the needed UAVs. For the system model, a Matérn Cluster Process (MCP) is used to describe the users' location in realistic scenarios. Based on that, we detail the proposed algorithms, and we derive the corresponding number expressions of the needed UAVs. Numerical results are used to confirm the derived expression and to evaluate the proposed 3-D placement strategies.**

***Index Terms*—3-D Placement Strategies, UAV, Wireless Networks.**

I. Introduction

In the new generation of cellular networks, the radio coverage and the wireless capacity are the critical issues for unexpected emergency scenarios, when conventional terrestrial networks are either damaged or crowded, or for temporary events, where there is a high density of users in a limited area, e.g., sports events. Recently, network flying platforms (NFPs) such as drones and unmanned aerial vehicles (UAVs) have been proposed as promising solutions for those issues [1–3]. In particular, owing to their mobility and flexibility, NFPs can be quickly and efficiently deployed to support cellular networks and enhance network quality-of-service (QoS) during the mentioned scenarios [1], [2]. To increase the advantages of using UAVs in NFP-based wireless networks, a UAVs placement strategy is needed.

This placement strategy is critical and is different from terrestrial cells placement due to the following reasons:

- Terrestrial base station (BS) locations are defined in 2-D space only. However, the UAVs placements should be defined in 3D space, where the optimal altitude of each UAV should be well defined to offer good coverage and to achieve the required QoS.
- The terrestrial BS coverage area is predefined. However, the UAV coverage area depends on its optimal dynamic location, which is unknown before the placement problem solution.
- The mobility and the flexibility in the deployment of the UAVs allow extra degrees of freedom, which is not the case for the terrestrial BSs.

As a result, an efficient UAV placement mechanism is needed to maximize the benefits of using UAVs in NFP-based wireless networks.

To the best of our knowledge, only few papers have addressed the multiple UAVs placement problems. In [4], the authors have studied the UAV placement under the assumption of fixed altitude and without considering the effect of different propagation environments, which presents limitations for this work. In [5], the impact of interference on the coverage of two UAVs has been investigated under a fixed UAV altitude assumption. The interference effects has been further analyzed in [6]. In this work the considered interference results from the presence of device to device transmissions. Different from the work in [4–6], the authors in [7] have addressed the previous issues, where they have proposed a placement strategy scheme that is considering the UAV altitude. To evaluate the enhancement of using UAV to assist the communication system, the author in [8], have evaluated the extended coverage at a certain altitude to confirm the advantage of using the UAVs, specially in the case of failure of terretrial base stations.

The previous presented work have been based on a specific altitude and a specific scenario, where the corresponding results are very limited and are not applicable for general cases. In addition, the used altitude are not related to the quality of service requirements. Moreover, a more realistic and efficient channel model that characterizes the air-to-ground communication should be used to present accurate and general results for different environments.

Recently, in [9], a 3-D placement algorithm for UAV-cells has been proposed to enhance the cellular networks. In this work the air-to-ground channel has been presented and used to jointly define the area to be covered, and the altitude of the UAV-cell under the target of maximizing the number of users covered by the UAV-cell.

All the above work have been focusing on a unique UAV placement problem, without considering the general multiple UAVs case in a predefined environment. In addition, a realistic modeling of the users locations has not been used.

In light of the aforementioned related work, our main contributions can be summarized as the follow:

- We propose two 3-D placement strategies of multiple UAVs in NFP-based wireless networks; The first strategy is based on a distributed placement algorithm that can be executed by the collaboration between the users and a mother UAV, the second strategy is central as it can be executed at a mother UAV to define the number and the optimal 3-D placement of the needed UAVs.
- To describe the system model, and different than the previous works, stochastic geometry is used in this paper, where we derive the number expressions of the needed UAVs for both proposed algorithms.

The remainder of this paper is organized as follows. The system model is presented in Section II. Section III introduces the proposed UAVs 3D placement algorithms, where the corresponding number expressions of the needed UAVs is detailed and derived. Based on that, the numerical results are presented in Section IV to confirm the derived expressions and to investigate the advantages of the proposed algorithms. Finally, conclusions are drawn in Section V.

II. System Model

We consider a NFP-assisted terrestrial cellular network, in which a mother UAV and a number of daughters UAVs are located in the space to serve a given number of terrestrial users. The users are assumed to be randomly located according to a Matérn Cluster Process (MCP). MCP is a stationary and isotropic Poisson cluster process generated by a set of daughter points independently and identically distributed (i.i.d.) around each point of a parent Poisson point process (PPP) [9]. In particular, the locations of the parent points are modeled as a homogenous PPP $\Phi_{\rm P}$ with density $\lambda_{\rm P}$ around which the daughter points are uniformly distributed in clusters with radius r. Let D_x be the set of daughter points for the cluster centered at $x \in \Phi_{\rm P}$. Based on that, the MCP can be presented by $\Phi = \cup_{x\in\Phi_{\rm P}}\{D_x\}$, where the number of points per cluster is a Poisson distributed random variable with mean $\bar{m}$. Consequently, the average density of users is equal to $\bar{m}\lambda_{\rm P}$. The optimal placement of the UAVs is the main contribution of this work, which will be detailed later. In this system model, and as shown in Fig. 1, we assume that each UAV is equipped with a directional antenna of adjustable beam-width. For simplicity, we assume that the azimuth and elevation half-

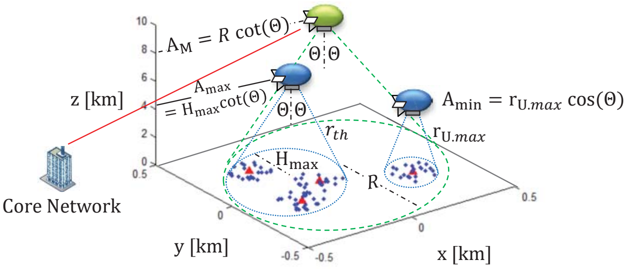


Fig. 1: The system model.

power beam-widths (HPBM) of the UAV antenna are equal, which are both denoted as 2Θ in radians (rad), with $\Theta \in [0, \frac{\pi}{2}]$ [10]. Thus, the ground coverage area for a located UAV at a given altitude A is the disk region on the ground with radius $r_{\rm B} = A\tan\Theta$ as presented in Fig. 1.
The general total air to ground (AtG) channel loss is expressed in dB as [11]

$$L_{\xi,{\rm U[dB]}} = L_{0,{\rm U[dB]}} + \eta_{\xi,{\rm U[dB]}}, \tag{1}$$

where $L_{0,{\rm U[dB]}}$ represents the free space path-loss (FSPL) between a user U and its corresponding UAV, which is expressed as

$$L_{0,{\rm U[dB]}} = 20\ \log_{10}\left(\frac{4\pi f_c r_{\rm U}}{C}\right), \tag{2}$$

with, f_c is the carrier frequency [Hz], C is the speed of light [m/s], and $r_{\rm U}$ is the distance between a user U and its corresponding UAV. The parameter $\eta_{\xi,{\rm U[dB]}}$ in (1) is a random variable that describes the excessive path-loss and its statistics is dependent on the propagation group ξ. The parameter ξ refers to the propagation group; $\xi = 1$ for the line of sight (LOS) group, and $\xi = 2$ for the non-LOS (NLOS) group. In general, the probability that a receiver belongs to a certain group depends on the altitude, A, of the UAV, and the urban statistical parameters. Let $p_{\xi,{\rm U}}$ denotes this probability, which is also called the group occurrence probability. Based on [11], [12], $p_{1,{\rm U}}$ can be expressed as follows

$$\begin{aligned} p_{1,{\rm U}} =& 1 - p_{2,{\rm U}} \\ =& \frac{1}{1 + a\exp\left(-b\left[\arctan\left(\frac{A}{h_{\rm U}}\right)\frac{180}{\pi} - a\right]\right)}, \end{aligned} \tag{3}$$

where, $h_{\rm U}$ is the horizontal distance between a user U and its corresponding UAV, and a and b are constant values that depend on the environment.
For each propagation group ξ at a given user U, the expression of the excessive path-loss $\eta_{\xi,{\rm U[dB]}}$ is written as [11]

$$\eta_{\xi,{\rm U[dB]}} = \bar{\eta}_{\xi,{\rm U[dB]}} + s_{\xi,{\rm U[dB]}} + f_{\xi,{\rm U[dB]}}, \tag{4}$$

where, $\bar{\eta}_{\xi,{\rm U[dB]}}$ represents the mean value, which depends on the elevation angle of the UAV, and $s_{\xi,{\rm U[dB]}}$ and $f_{\xi,{\rm U[dB]}}$ represent the random shadowing and small-scale fading factors, respectively. Based on that, the value of the instantaneous received air-to-ground signal to noise ratio (SNR) at user U can be expressed as follows

$$\gamma_{\rm U} = \sum_{\xi=1}^{2} p_{\xi,{\rm U}} \frac{P_{\rm T}\ \ S_{\xi,{\rm U}}\ F_{\xi,{\rm U}}}{L_{0,{\rm U}}\ \ \bar{\eta}_{\xi,{\rm U}} N_0}, \tag{5}$$

where, $F_{\xi,{\rm U}}$ is the power in Watt of the small-scale fading, which is assumed to be Rayleigh fading for NLOS and Ricean fading for LOS, and $S_{\xi,{\rm U}}$ is the general log-normal shadowing power in Watt, which is expressed as [13]

$$S_{\xi,{\rm U}} = \exp\Big(\sigma_{\xi,{\rm U}} N\Big), \tag{6}$$

where, N is a normal variable with zero mean and unit variance, $\sigma_{\xi,{\rm U}} = \frac{\ln(10)}{10}\sigma_{\xi,{\rm U[dB]}}$, and $\sigma_{\xi,{\rm U[dB]}}$ is the decibel standard deviation provided by the AtG model in [13, (Eq. 9)] and is expressed as follows

$$\sigma_{\xi,\mathrm{U[dB]}} = a_{\xi} \exp\Big(- b_{\xi} \arctan\Big(\frac{A}{h_{\mathrm{U}}}\Big)\frac{180}{\pi}\Big). \tag{7}$$

Let $A_{\max}$ denotes the maximum amplitude of the UAVs, where the RSS at each point inside the corresponding coverage area, with radius $H_{\max}$, is larger or equal to a predefined RSS threshold (RSS_{th}). The expressions of $A_{\max}$ and $H_{\max}$ are derived as follows:
To fulfill the constraint of the RSS_{th}, the RSS at a given user located at the edge of the UAV coverage area should be equal to RSS_{th}. Based on (5), the RSS at this user can be expressed as follows

$$RSS_{th} = \sum_{\xi=1}^{2} p_{\xi,\mathrm{U}} \frac{P_{\mathrm{T}}}{L_{0,\mathrm{U}}\ \bar{\eta}_{\xi,\mathrm{U}}}, \tag{8}$$

where, the horizontal distance between the UAV and U is equal to $H_{\max}$, and the UAV amplitude is equal to $A_{\max} (= H_{\max} \tan(\Theta))$. Now, based on (2), (3), and (8), the expression of $H_{\max}$ is given by

$$\begin{aligned} H_{\max} &= A_{\max} \tan(\Theta) \\ &= \frac{C\cos(\Theta)}{4\pi f_C}\sqrt{\frac{P_{\mathrm{T}}}{RSS_{th}}\left[\frac{\bar{\eta}_{2,\mathrm{U}} - \bar{\eta}_{1,\mathrm{U}}}{\bar{\eta}_{1,\mathrm{U}}\bar{\eta}_{2,\mathrm{U}}\left[1+a\exp(-b(\Theta\frac{180}{\pi}-a))\right]}+\frac{1}{\bar{\eta}_{2,\mathrm{U}}}\right]} \end{aligned} \tag{9}$$

In the following section, and based on this system model, we present and detail the proposed UAVs 3D placement strategies.

III. UAVs 3-D Placement Strategies

The main notations used throughout the proposed algorithms and the paper are presented in Table 2.

TABLE I: Main Used Notations

Notation	Definition
R	Side length of the considered square area
λ_{P}	User clusters' density
r	User clusters' radius
$\bar{m}$	Average number of users per cluster
P_T	UAV transmit power
RSS_{th}	RSS threshold
2Θ	The azimuth and elevation HPBW of the UAV antenna
$A_{\max}$	Maximum altitude of the UAVs
$H_{\max}$	Maximum radius of the UAV coverage area
$\hat{N}_{\mathrm{UAV}}$	Number of the needed UAVs.
$\hat{\mathbf{V}}_{\mathrm{X}}$	X coordinate vector of the UAVs' optimal placement
$\hat{\mathbf{V}}_{\mathrm{Y}}$	Y coordinate vector of the UAVs' optimal placement

A. Distributed Placement Algorithm (DPA)

The DPA is proposed to be executed jointly between the users and the mother UAV. This algorithm can be summarized as follows:
By using the value of $H_{\max}$, we define the coordinates vectors ($\mathbf{V}_{\mathrm{X}}$ and $\mathbf{V}_{\mathrm{Y}}$) of all the needed UAVs that cover the considered area with a regular Hexagon pattern of radius $H_{\max}$ as shown in Fig. 2. After that, the mother UAV Broadcasts the locations of all the UAV, with the corresponding reference numbers, to all the users. Next, each user transmits the reference number of its nearest UAV to the mother UAV. Based on that, the mother UAV selects the number and the locations of the UAVs that are covering at least $N_{U,\min}$ users.

Distributed Placement Algorithm (DPA)

1: **Inputs:** $R,\ r,\ P_{\mathrm{T}},\ RSS_{th},\ \Theta,\ N_{U,\min}$
2: **Outputs:** $\hat{N}_{\mathrm{UAV}}, \hat{\mathbf{V}}_{\mathrm{X}},\ \hat{\mathbf{V}}_{\mathrm{Y}}$
3: • Evaluated $H_{\max}$ as presented in (10);
4: • Define the coordinates vectors ($\mathbf{V}_{\mathrm{X}}$ and $\mathbf{V}_{\mathrm{Y}}$) of the (N_{UAV}) UAVs that cover the considered area with a regular Hexagon pattern of radius $H_{\max}$ as shown in Fig. 2
5: • Broadcasting the locations of all the UAV by the mother UAV to all the users.
6: • Each user selects the nearest LA UAV and send its reference number to the mother UAV.
7: • The mother UAV selects the number ($\hat{N}_{\mathrm{UAV}}$) and locations ($\hat{\mathbf{V}}_{\mathrm{X}},\ \hat{\mathbf{V}}_{\mathrm{Y}}$) of the UAVs that are covering at least $N_{U,\min}$ users. =0

Let N_{UAV} denotes the number of the UAVs that cover all the considered area, and $\hat{N}_{\mathrm{DPA}}$ denotes the number of the needed UAVs within the proposed DPA algorithm. Based on the presented system model, N_{UAV} can be evaluated as the ratio between the total considered area, $(2\ R)^2$, and the area of a regular hexagon with a radius $H_{\max}$. Consequently, N_{UAV} is expressed as follows:

$$N_{\mathrm{UAV}} = \left\lceil \frac{2(2R)^2}{3\sqrt{3}H_{\max}^2} \right\rceil, \tag{10}$$

where, $\lceil . \rceil$ is the ceiling function. Now, $\hat{N}_{\mathrm{DPA}}$ can be defined as N_{UAV} times $\Pr\big(N_{\mathrm{U}} \geq N_{U,\min}\big)$, where $\Pr\big(N_{\mathrm{U}} \geq N_{U,\min}\big)$ presents the probability that at least $N_{U,\min}$ users exist in the coverage area of a given UAV, which is a disc area of radius $H_{\max}$. Based on that $\hat{N}_{\mathrm{DPA}}$ can be written as follows

$$\begin{aligned} \hat{N}_{\mathrm{DPA}} &= N_{\mathrm{UAV}}\ \Pr\big(N_{\mathrm{U}} \geq N_{U,\min}\big) \\ &= N_{\mathrm{UAV}}\ \Big[1 - \Pr\big(N_{\mathrm{U}} < N_{\mathrm{U,min}}\big)\Big]. \end{aligned} \tag{11}$$

By assuming that $N_{\mathrm{U,min}}$ should be larger than $\bar{m}/2$, and by considering a given disc area of radius $H_{\max}$, $\Pr\big(N_{\mathrm{U}} < N_{\mathrm{U,min}}\big)$ can be evaluated as the probability that there is no center of a user cluster is included in this disc area. As the centers of the user clusters are randomly distributed according to PPP with density λ_{p}, and according to [14], the expression of $\Pr\big(N_{\mathrm{U}} < N_{\mathrm{U,min}}\big)$ can be approximated as follows

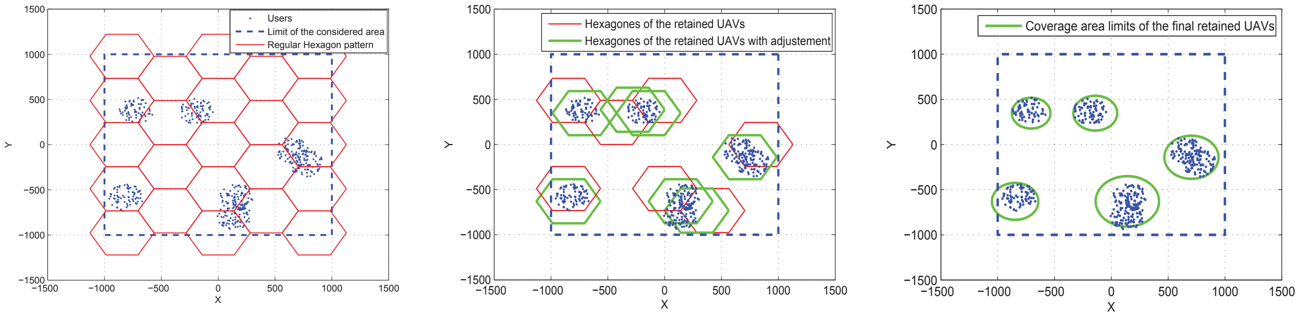
$$\Pr\big(N_{\mathrm{U}} < N_{\mathrm{U,min}}\big) = \exp\Big(- \lambda_p \pi H_{\max}^2\Big). \tag{12}$$

and. the final expression $\hat{N}_{\mathrm{DPA}}$ is given by

$$\hat{N}_{\mathrm{DPA}} \approx N_{\mathrm{UAV}}\ \Big[1 - \exp\Big(- \lambda_p \pi H_{\max}^2\Big)\Big] \tag{13}$$

B. Centric Placement Algorithm (CPA)

For CPA, the placement strategy is proposed to be executed at the mother UAV, by using the following algorithm:



(a) Initializing (b) Step 1 (c) Step 2 & 3

Fig. 2: CPA Steps.

Similar to the proposed DPA, the value of H_{max} should be evaluated first based on (9). Then, the coordinates vectors $\mathbf{V}_{\text{X}}$ and $\mathbf{V}_{\text{Y}}$ can be defined. Based on that, and for each UAV k, we define its locations matrix as follows

$$\mathbf{P}(i,j,k) = \begin{cases} 1; & \text{if } \sqrt{(\mathbf{V}_{\text{X}}(k)-i)^2+(\mathbf{V}_{\text{Y}}(k)-j)^2} \leq H_{\text{max}}, \\ & \forall k \in \{1,..,N_{\text{UAV}}\}, \{i,j\} \in \{1,..,R+H_{\text{max}}\}, \\ 0; & \text{Otherwise.} \end{cases} \tag{14}$$

Now, for the users locations, we define the corresponding matrix $\mathbf{U}$ as follows.
After initialize all the elements of $\mathbf{U}$ to zeros, the final matrix is evaluated as follows

$$\mathbf{U}(i,j) = \mathbf{U}(i,j) + \begin{cases} 1; & \text{if } \Big((\lceil u_{\text{x}} \rceil, \lceil u_{\text{y}} \rceil) = (i,j)\Big) \forall\, U \in \Phi, \\ 0; & \text{Otherwise.} \end{cases} \tag{15}$$

After that, by using the matrix operations as shown in Step 1 of the Algorithm, only the UAVs that are covering at least $N_{U,\text{min}}$ users are retained as shown in the example of Fig. 2b. Then, an adjustment procedure can be done to place each retained UAV at the center of the corresponding covered set of users. This adjustment can be done as follows:

$$(\mathbf{V}_{\text{X}}(k), \mathbf{V}_{\text{Y}}(k))_{(k \in \{1,..N_{\text{UAV}}\},\ \mathbf{I}_{\text{P}}(k)=1)} = \underset{\substack{(\mathbf{V}_{\text{X}}(k)+i, \mathbf{V}_{\text{Y}}(k)+j) \\ \{i,j\} \in \{-H_{\text{max}},0,H_{\text{max}}\}}}{\arg\min} \sum_{U \in C_k} \sqrt{(\mathbf{V}_{\text{X}}(k)+i-x_{\text{U}})^2+(\mathbf{V}_{\text{Y}}(k)+j-y_{\text{U}})^2}, \tag{16}$$

where, C_k denotes the coverage area of UAV index k, and x_{U}, and y_{U} are the coordinates of user U. For the next step, only the UAVs with minimum inter-distance of H_{max} will be retained as presented in Fig. 2c. In Step 3, an adjustment of the retained UAVs' altitudes can be done according to the farthest user in the corresponding coverage area, and hence an increase of the average RSS can be observed at the users. Finally, the number and optimal 3-D positions of the needed UAVs can be fixed.
Mathematically speaking, the expression of $\hat{N}_{\text{CPA}}$ can be evaluated as the average number of the user clusters, with the constraint of the minimum inter-distance H_{max}. Accordingly, and based on the retaining probability in the Matern Hard Core Process (MHCP) [14], $\hat{N}_{\text{CPA}}$ is expressed as follows:

$$\hat{N}_{\text{CPA}} = \frac{\left[1-\exp(-\lambda_{\text{p}} \pi H_{\text{max}}^2)\right]\left[2(R-r)\right]^2}{\pi H_{\text{max}}^2} \tag{17}$$

Centric Placement Algorithm (CPA)

Inputs: R, r, P_{T}, RSS_{th}, Θ, $N_{U,\text{min}}$
Outputs: $\hat{N}_{\text{UAV}}$, $\hat{\mathbf{V}}_{\text{X}}$, $\hat{\mathbf{V}}_{\text{Y}}$
• Evaluated H_{max} as presented in (10);
• Define the coordinates vectors ($\mathbf{V}_{\text{X}}$ and $\mathbf{V}_{\text{Y}}$) of the (N_{UAV}) UAVs that cover the considered area with a regular Hexagon pattern of radius H_{max} as shown in Fig. 2
• Define the UAVs' locations matrix $\mathbf{P}$ as presented in (12)
• Define the users' locations matrix $\mathbf{U}$ as presented in (13)
• Initialize: $\hat{N}_{\text{UAV}} = N_{\text{UAV}}$
• Initialize: $\mathbf{I}_{\text{P}} = [1]_{1 \times T N_{\text{UAV}}}$: UAV retaining indicator vector
• **Step 1**: Retaining each UAV that is covering at least $N_{U,\text{min}}$ users
for $k = 1$ to N_{UAV} **do**
  if (sum($\mathbf{P}(:,:,k)$ $\times$ $\mathbf{U}$) $\geq N_{U,\text{min}}$) **then**
    Adjustment of the retained UAV index k as presented in (15)
  else
    $\mathbf{I}_{\text{P}}(k) = 0$; $\hat{N}_{\text{UAV}} = \hat{N}_{\text{UAV}} - 1$;
  end if
end for
• **Step 2**: Retaining the UAVs with minimum inter-distance of H_{max}
for $(k \neq l \in \{1,..N_{\text{UAV}}\})$ **do**
  if ($\mathbf{I}_{\text{P}}(k) = 1) \cap (\mathbf{I}_{\text{P}}(l) = 1) \cap (\text{d}_{k,l} \leq H_{\text{max}}$) **then**
    $\hat{N}_{\text{UAV}} = \hat{N}_{\text{UAV}} - 1$; $\mathbf{I}_{\text{P}}(l) = 0$
  end if
end for
$n = 1$
for $k = 1$ **to** N_{UAV} **do**
  if ($\mathbf{I}_{\text{P}}(k) = 1$) **then**
    $\hat{\mathbf{V}}_{\text{X}}(n) = \mathbf{V}_{\text{X}}(k)$; $\hat{\mathbf{V}}_{\text{Y}}(n) = \mathbf{V}_{\text{Y}}(k)$; $n = n + 1$;
  end if
end for
• **Step 3**: Adjustment of the retained UAVs' altitudes

IV. Numerical results and Discussions

In this section, numerical results are presented to investigate the performance of the proposed algorithms and to confirm the corresponding derived number expressions of the needed

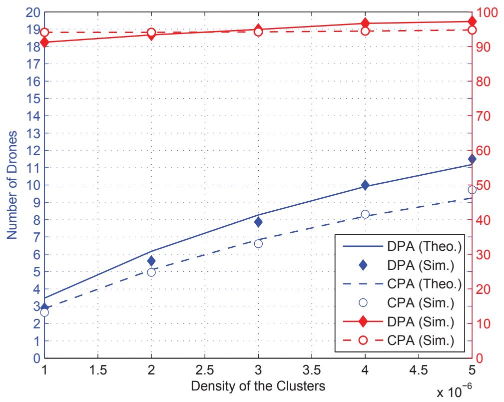


Fig. 3: Number of the needed UAVs and percentage of covered users vs. λ_{P}, with $P_{\text{T}} = 3$ dB.

UAVs. The used simulation parameters are as follows: $R = 900$ m, $r = 100$ m, $\bar{m} = 50$, $RSS_{\text{th}} = -90$, $f_c = 2.5$ GHz, $\Theta = \frac{\pi}{6}$ rad, $\eta_{1,\text{U[dB]}} = 1$ dB, $\eta_{2,\text{U[dB]}} = 20$ dB, $a = 9.61$, $b = 0.16$, and $N_{U,\min} = \frac{\bar{m}}{2}$.

In Fig. 3, we present the number of the needed UAVs and the percentage of covered users vs. λ_{P} for the proposed algorithms, with $P_{\text{T}} = 3$ dB. As shown in this figure, the number of the needed UAVs within CPA is lower than that of the DPA. This is due to the fact that, for the CPA, the adjustment and eliminating steps reduces the number of the needed UAVs, which is not the case in the DPA. For low value of λ_{P}, the CPA outperforms the DPA in term of covered users percentage, which is not the case for high value of λ_{P}. This is because, for the first case, the adjustment procedure within the CPA results in a better coverage of the users positions with a high UAVs retaining probability. However, for large values of λ_{P}, and within the CPA, the needed number of UAVs increases, which decreases the retaining probability. In this case, as there are no adjustment and eliminating procedures within the DPA, the number of UAVs increases, which results in a better percentage of covered users than that of the CPA.
Fig. 4 presents the number of the needed UAVs vs. P_{T}, with $\lambda_{\text{P}} = 3e - 6$ m^{-2}. In this figure, it is clear that the number of the needed UAVs for both proposed algorithms decreases with the increased value of the UAVs' transmit power. This is because, by increasing P_{T}, the UAV coverage area increases, which results in a decrease of the number of the needed UAVs.

V. Conclusion

Two 3-D placement strategies of UAVs in NFP-based wireless networks have been proposed in this paper. The two strategies are based on distributed and central placement algorithms. To evaluate the proposed strategies in a realistic system model, a Matérn Cluster Process (MCP) is used to describe the users' location. Based on that, the number expressions of the needed UAVs for both algorithms are detailed and derived. Numerical results are used to confirm the derived expression and to evaluate the proposed 3-D placement strategies. As an extension of this work, and to enhance the performance of NFP-based wireless networks, we propose to present and evaluate new mode selection schemes for device to device (D2D) enabled NFP-based wireless networks.

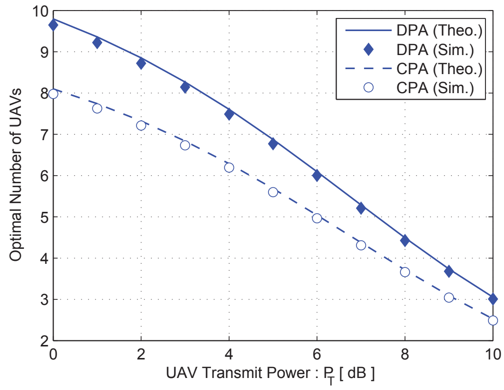


Fig. 4: Number of the needed UAVs vs. P_{T}, with $\lambda_{\text{P}} = 3e - 6$ m^{-2}.

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