# Review: Circle Packing Theory Based System Modeling in Unmanned Area Vehicle Deployment Optimization

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**ABSTRACT**

Numerous applications of UAVs cannot be overemphasized which include providing communication links for emergency purposes and temporary availability in remote locations. The use of directional antenna facilitates the horizontal plane circular 2D shape of the communication link coverage area of Aerial BS or UAV. Hence, in many literatures, CPT was discovered to be an important basic tool in formation of different system models for optimization of deployment of Aerial BS for possible maximal user density within the covered region. This paper presented such models for study to enhance possibilities of proffering a CPT based procedure for developing novel algorithms or system models for future deployments of Aerial base stations.

**KEYWORDS:** Aerial BS, CPT, Optimization, System Model, UAV

## 1. INTRODUCTION

Unmanned Aerial Vehicles (UAV) which are also labelled as Aerial Topedo (AP), Autonomous Controlled Vehicles (ACV), Radio Controlled Vehicles (RCV), Remote Piloted Vehicles (RPV) and drones can be described as autonomous aerial flying gadgets or objects without any physical pilot or board (Li et al., 2019; (PennState College of Earch and Mineral Sciences, 2018)(Tor et al., 2020). UAV are used for many applications including telecommunication purposes. Its applications in telecommunications include space exploration, base stations (BS) for mobile systems, Access Point (AP) or hotspot for wireless network . Aerial Base Station (Aerial BS) is appellation given to UAV that for electronic communication linkage or transceiver purposes between among one more communication devices or ground users (Alzenad et al., 2017; Mozaffari et al., 2016; Shakhatreh et al., 2017; Sun & Masouros, 2018). Mobile UAVs can serve as ground sensors for detecting network devices or communication links (Mozaffari, 2016).This paper is a review of some literatures on deployment of Aerial BSs (UAVs) with utmost interest in the use of Circle Packing Theory (CPT) methods for optimisation modelling techniques. It is major aim is to give better foundational understanding in initiating system modelling for Aerial BS Coverage. Next section discusses CPT techniques and UAV in relation to reviewed literatures. The followed section discusses the CPT based optimisation system model for the deployment of UAVs. Finally, a general procedural steps in establishing CPT based optimisation model for deployment of multiple UAVs were written based on observation and suggestions from many of the reviewed works on the topic was presented.

## 2. REVIEWED LITERATURE AND METHODS

### 2.1 CIRCLE PACKING THEORY IN RELATION TO AERIAL BASE STATIONS

UAVs can be utilized as dynamic Aerial BSs which are not fixed in specific locations for providing wireless hotspot or network service for temporary or dynamic purposes (Alzenad et al., 2017; Sun & Masouros, 2018). Further advanced works were carried out for more possibility of providing coverage of target ground users (Cicek, n.d.; Shakhatreh et al., 2017; Vilor et al., n.d.; Zhao et al., 2021). This development of using more than one Aerial BSs called for optimization techniques for the use of multiple drones deployment to maximally increase probability of service coverage of ground users by each drone and all the drones in general.

The 3D image of the beamwidth of high efficient directed antenna carried by each drone projected a circle form as 2D image of the radiated beam on the horizontal plane. Therefore, each UAV are located at a distance or altitude, *h*, to the centre of the circle. CPT is a technique of optimally occupying a space with different non overlapping circles (Gaspar & Tarnai, 2000; Lyu et al., n.d.; Shakhatreh et al., 2017; Sun & Masouros, 2018). Hence, it is applied in deployment of different Aerial BSs to project a non overlapping coverage circles on the horizontal plane. Furthermore, CPT based optimization techniques in deployment of Aerial BSs is a system model that ensures that each UAV are deployed in a location at a height and pathloss that guaranteed possible maximum user density and possible maximum coverage probability, possible minimum power consumption and no overlapping coverage area or inter-cell interference (Shakhatreh et al., 2017; Sun & Masouros, 2018; Yuheng et al., 2019; Zhao et al., 2021). The first optimization system model was based on CPT and other variants were related to it.
Position or location of each Aerial BS ($q$ *or* $(x_i,y_i)$) is a specific point at an altitude, *h*, which is directly at the centre of its coverage area with an assumption that it is a perfect circle at the horizontal plane. This location point is giving by GPS reading from the gps sensor attached to the UAV. The beamwidth$(\phi)$of the directional antenna is used to obtained the inclination angle $(\theta)$of each ground user. Figure I depicts the proper illustration of the parameters for basic understanding of CPT based system model for Aerial BS (Gao et al., 2018; Mozaffari et al., 2016; Zhao et al., 2021).

### 2.2 Aerial BS Deployment System Model using CPT based Optimization Techniques

Optimization techniques are explored for deploying multiple Aerial Base Stations to cover maximum number of ground users per UAV over a target area. The first optimization technique algorithm was based on Circle Packing Theory (CPT) which served as a benchmark for evaluation of other algorithms (Mozaffari et al., 2016; Sun & Masouros, 2018). Based on other reviewed works, high precision GPS system is used to assumed location of ground users with no communication services as part of initialization process for the Aerial BS deployment techniques. The research works considered effects of both 'Line of Sight' (LOS) and 'Non Line of Sight' (NLOS) Links on the air to ground service to be provided (Alzenad et al., 2017; Caillouet et al., 2017; Shakhatreh et al., 2017). Linear Approximation Algorithm and K-means Clustering Algorithm were modification of basic CPT based algorithms for better performance in term of coverage probability using multiple UAVs deployment for the service (Caillouet et al., 2017; Lyu et al., n.d.; Mozaffari et al., 2016; Sun & Masouros, 2018).

### 2.2.1 System Model using Basic CPT

Different authors efficiently deployed multiple UAV with directional antennas acting as wireless base station that provide high coverage probability for ground users (Cicek, n.d.; Mozaffari et al., 2016; Sun & Masouros, 2018; Zhao et al., 2021). Mozaffari etal (2016) expressed downlink coverage probability as a function of the altitude (height) and antenna and antenna gain. CPT was used to determine the 3D locations of the UAVs by maximizing the total coverage area while maximizing lifetime of the UAVs (Mozaffari et al., 2016).
Summarily, for the basic CPT deployment techniques, the following formula and definitions of notations were utilized based on the aforementioned authors cited above:

$$r_{ik} = \sqrt{(x_i - x_{ck})^2 + (y_i - y_{ck})^2} \quad (1)$$

$$\theta_{ik} = tan^{-1}\left(\frac{h_k}{r_{ik}}\right) \quad (2)$$

Where:

$r_{ik}$ = the distance between ith ground user and kth UAV

$\theta_{ik} = The elevation angle$ in $radian$

$(x_i, y_i) = location of ground user i$ in $the set M (of the total target area)$

$(x_{ck}, y_{ck}) = location of k_{th} UAV$ or $Aerial BS on the horizontal plane at altitude h_k$

Air to ground transmission parameters like pathloss has great effect in determining the optimal location of the drone and maximizing the user density of its covered places. Pathloss consideration for both Line of Sight (LOS) and Non

Line of Sight (NLOS) effects on transmission for each ground user and its corressponding Aerial BS as transmitter is expressed as $PL(\theta_{ik},r_{ik})$ and shown in equation (3) below.

$$PL(\theta_{ik},r_{ik}) = \frac{A}{1 + aexp\left(-b\left(\frac{180^0}{\pi}\theta_{ik} - a\right)\right)} + 20log\left(\frac{r_{ik}}{cos\theta_{ik}}\right) + B(3)$$

where:

$$A = \eta_{LOS} - \eta_{NLOS}(4)$$

$$B = 20log\left(\frac{4\pi}{c}\right) + 20log(f_c) + \eta_{NLOS}(5)$$

$$\eta_{LOS} = excessiveLOSloss; \eta_{NLOS} = excessiveNLOSloss$$

$$C = SpeedofLight; f_c = carrierfrequency$$

Coverage area per Aerial BS is $R_k$(given a propagation path loss PL ($\gamma_{th} = thresholdpathloss$) at altitude $h_k$and distance $r_{ik}$).

$$R_k = r_{ik}|PL(h_k,r_{ik}) = \gamma_{th}(6)$$

The threshold path loss was finally expressed as

$$\gamma_{th} = \left[\frac{A}{1 + aexp\left(-b\left(\frac{180^0}{\pi}\theta_{opt} - a\right)\right)}\right] + 20log\frac{R^*_k}{cos\theta_{opt}} + B(7)$$

This methods involved solving for maximum coverage distance $R_k$ (which is staredabove ($R^*_k$) for a given altitude $h_k$. This was assumed to be equal for all the circle placement or coverage areas for Aerial BSs.

*Hence,* $R_k = R^*_k = R$ *; So,*

$$h_k = H = Rtan\theta_{opt}(8)$$

The first UAV was placed with the below optimization objective function, convex constraints and set point variables:

$$\underset{x_{c1},y_{c1},u_i}{maximize} \sum_{i \in M} u_i \ (9)$$

*subject to*

$$(x_i - x_{c1})^2 + (y_i - y_{c1})^2 \leq R^2 + M(1 - u_i)(10)$$

$$u_i \in [0,1]; \forall i \in M(11)$$

*For second UAV placement:*

$$\underset{x_{c2},y_{c2},u_i}{maximize} \sum_{i \in M} u_i \ (12)$$

subject to

$$(x_i - x_{c2})^2 + (y_i - y_{c2})^2 \leq R^2 + M(1 - u_i)(13)$$

$$(x_{c2} - x_{c1})^2 + (y_{c2} - y_{c1})^2 \geq 4R^2(14)$$

$$u_i \in [0,1]; \forall i(15)$$

For subsequent kth UAV placement while avoiding any interference from the cell or overlapping with coverage area of previously deployed jth UAV and solving for Mixed Integer Non Linear Programming (MINLP) problems, optimization system model below is a useful tool that had been used by some authors. It acts as a general system model for deployment of multiple Aerial BS.

$$\underset{x_{ck},y_{ck},u_i}{maximize} \sum_{i \in M} u_i \ (16)$$
$$\text{subject to}$$
$$(x_i - x_{ck})^2 + (y_i - y_{ck})^2 \leq R^2 + M(1 - u_i)(17)$$
$$\left(x_{ck} - x_{cj}\right)^2 + \left(y_{ck} - y_{cj}\right)^2 \geq 4R^2(18)$$
$$u_i \in [0,1]; \forall i \in M; j = 1,2,3,\ldots,k-1(19)$$

**2.2.2 The System model using Linear Approximation (LA) Algorithm Techniques**

The CPT based model was modified by converting the non-convex constraint (equation 18), $\left(x_{ck} - x_{cj}\right)^2 + \left(y_{ck} - y_{cj}\right)^2 \geq 4R^2$, to convex form (equation 21), $(x_i - x_{ck}^m)^2 + (y_i - y_{ck}^m)^2 \leq R^2 + M(1 - u_i)$, through linear approximation method that simplified the MINLP problems to an easily solved optimized model below (Alzenad et al., 2017; Sun & Masouros, 2018).

$$\underset{x_{ck}^m,y_{ck}^m,u_i}{maximize} \sum_{i \in M} u_i \ (20)$$
$$\text{subject to}$$
$$(x_i - x_{ck}^m)^2 + (y_i - y_{ck}^m)^2 \leq R^2 + M(1 - u_i)(21)$$
$$(x_{ck}^m, y_{ck}^m) \in C_k^m(22)$$
$$u_i \in \{0,1\} \forall i \in M; j = 1,2,3,\ldots,k-1(23)$$

From this LA model, $(x_{ck}, y_{ck})$was obtained as the location of the kth UAV for a maximum number of covered (serviced) users, $N_{max} = N_m$ , at mth feasible region. The technique was observed to cover larger portion of the remaining unserviced area and users than the previous basic CPT model (Sun & Masouros, 2018). The challenges of LA is observed to be iterative computational burden for its successful one by one deployment processes to avoid overlapping.

**2.2.3 The System model using K means Clustering Algorithm Techniques**

Sun & Masourous (2018) proposed the use of clustering for efficient deployment with simple computational process. K-means clustering was used to divide the total target service area to k number of sub-areas that formed a Voronoi diagram with possible radius of the covered serviced area of kth UAV (with no ICI) as $R_k$ which resulted into a MINLP Optimization without non-convex constraints as expressed by the given model below (Munaye et al., 2019; Sun & Masouros, 2018)

$$\underset{x_{ck},y_{ck},u_i}{maximize} \sum_{i \in M} u_i \ (24)$$
$$\text{subject to}$$
$$(x_i - x_{ck})^2 + (y_i - y_{ck})^2 \leq R_k^2 + M(1 - u_i)(25)$$
$$y_{ck} - a_{kl}x_{ck} - b_{kl} + \frac{R_k}{cos(|a_{kl}|)} \leq 0; (26)$$
$$if m_{ky} - a_{kl}m_{kx} - b_{kl} \leq 0, y_{ck} - a_{kl}x_{ck} - b_{kl} + \frac{R_k}{cos(|a_{kl}|)} \geq 0; (27)$$
$$if m_{ky} - a_{kl}m_{kx} - b_{kl} \geq 0, u_i \in \{0,1\} \forall i \in Mk = 1,2,3,\ldots,K; l = 1,2,3,\ldots,N_{kl}(28)$$

The k means clustering enhances this technique because it gave the model opportunities to have flexibility or scalability. It means that the coverage radius of each UAV is based size of its allocated cluster and user density for allocated sub-cluster for the sake of flexibility and scalability. Furthermore, it has an advantage of simultaneous deployment of of multiple UAVs without interference with better performance that the two previous models. Once the cluster segmentation has been done by K-means, the deployment of all the Aerial BS can be done simultaneously.

**2.2.4 System Model using CPT and Considering Inter Cell interference**

The initial methods are not taking special cognisant of path loss in their models apart from avoidance of overlapping of the coverage circle. Therefore, model that took care of losses due to interference and pathloss was developed as another variant CPT based UAV optimized deployment techniques (Mozaffari et al., 2016; Shakhatreh et al., 2017). Below are the equations and notations that lead to a general optimization model that consider path loss.

$$G(\phi)_{3dB} = \frac{29000}{\theta_B^2} \quad (29)$$

$$G = \{ \begin{matrix} 3dB, \frac{\theta_B}{2} \leq \phi \leq \theta_B \\ g(\phi), otherwise \end{matrix} \quad (30)$$

$$P_{r,j}(dB) = \{ \begin{matrix} P_t + G_{3dB} - L_{dB} - \phi_{LOS} \\ P_t + G_{3dB} - L_{dB} - \phi_{NLOS} \end{matrix} \quad (31)$$

$$L_{dB} = 10nlog\left(\frac{4\pi f_c d_j}{C}\right) \quad (32)$$

$$n \geq 2 = ThePathLossExponent$$

where :

$$\theta_B = halfbeamwidthofthedirectionalantenna \in degrees$$

$$\phi = \text{sector angle in degrees}$$

$$P_{r,j}(dB) = TheReceivedsignalpoweratas pecificuserlocation \text{from} thejthUAV$$

$$L_{dB} = \text{Path Loss}$$

$$Thevariancedependsontheelevationangle \text{and} typeofenvironment$$

$$\sigma_{LOS}(\theta_j) = k_j exp(-k_z \theta_j) \quad (33)$$

$$\sigma_{NLOS}(\theta_j) = g_i exp(-g_z \theta_j) \quad (34)$$

$$\theta_j = sin^{-1}(h/d_j) \quad (35)$$

$$\theta_j = Elevationanglebetweentheuser \text{and} UAV k_1, k_2 \text{and}$$
$$g_2 areconstantvaluesdependingontheenviroment.$$

$$P_{LOS} = \alpha\left(\frac{180}{\pi}\theta_j - 15\right)^{\gamma} \quad (36)$$

where :

$$P_{LOS} = LineofSightProbability$$

$$P_{NLOS} = NonLineofSightProbability$$

$$\alpha \text{and} \gamma areconstantdeterminedbytheenviromentimpact.$$

$$P_{NLOS} = 1 - P_{LOS} \quad (37)$$

$$P_{NLOS} = 1 - \alpha\left(\frac{180}{\pi}\theta_j - 15\right)^{\gamma} \quad (38)$$

For optimal development of multiple UAV, Coverage Probability for a ground user located at a distance r from the beam projection of the jth UAV on the target horizontal area surface is given as

$$P_{cov} = P_{LOS,j} Q\left(\frac{P_{min} + L_{dB} - P_t - G_{3dB} + \mu_{LOS}}{\sigma_{LOS}}\right) + P_{NLOS,j} Q\left(\frac{P_{min} + L_{dB} - P_t - G_{3dB} + \mu_{LOS}}{\sigma_{NLOS}}\right) \quad (39)$$

$$P_{min} = 10log(\beta N + \beta \bar{I}) \quad (40)$$

where:

$$Pmin = Minimumreceivedpowerrequiredthatcouldbedetedtedbythegroundusers.$$
$$N = Noisepower$$
$$\beta = Signal\text{to}NoiseplusInterferenceRatio$$
$$\bar{I} = \text{Mean}interferencepowerreceived\text{from}thekthnearestUAV_k$$
$$\bar{I} \approx P_t g(\phi)\left[10^{\frac{(-\mu_{LOS,k})}{10}} P_{LOS,k} + 10^{\frac{(-\mu_{NLOS,k})}{10}} P_{NLOS,k}\right]\left(\frac{4\pi f_c d_k}{C}\right)(41)$$

provided that

$$r \leq htan\left(\frac{\theta_B}{2}\right)(42)$$

$$r_u = max\{r|P_{cov}(r, P_t, \theta_B) \geq \epsilon\}(43)$$

The mean interference is a reasonable approximation for the interference that leads to a tractable coverage probability expression. Equation 42 shows that a user can be covered if it in the coverage range of a directional antenna with beamwidth $\theta_B$ . The above equation for $P_{cov}$ (equation 39) shows that changing the altitude has effect on the coverage by affecting so many parameters including distance, d, $P_{LOS}$ and feasible coverage radius, r (as given by equation 39, 41 and 42).

In order to mitigate interference, there will be a trade off of increment in transmitting power as depicted by equation 40 and41. As the height or altitude of UAV increases, path loss, LOS probability and radius of feasible coverage region increases as shown by equation 41 and equation 42. Furthermore, equation 41 illustrated the fact that as the number of UAV increases, distance between UAV decreases but inter-cell interference (ICI) increases.

$r_u$ represents the coverage radius of the UAV. It is the maximum range within which the probability that a user is covered is greater than a specified threshold. It depends on:

1. the transmit power, $P_t$ ;
2. the antenna beamwidth, $\theta_B$;
3. the threshold distance for the UAV coverage radius, $\epsilon$ ;
4. number of UAVs and
5. Locations or positions of UAVs.

Conditions for covering the target area using multiple UAVs and CPT techniques are:

1. Each UAV must be located in a position,$q_{uav}$, that maximizes the covered area;
2. Overlapping of the covered area must be avoided.
3. Each UAV must be planned to use a minimum transmit power so as to maximize their coverage lifetime.
4. For equal coverage radius, the coverage lifetime can be maximized by placing all UAVs at an equal altitude but horizontal plane locations that satisfies item 1 and 2.

Circular coverage area of each UAV is formulated as

$$\left(\bar{r}^*, h, r_u^*\right) = argmaxM. r_u^2, j \in \{1.....M\}(44)$$
$$subject\text{to}$$
$$||\vec{r_j} - \vec{r_k}|| \geq R_u j \neq k \in \{1.....M\}(45)$$
$$||\vec{r_j} + \vec{r_u}|| \leq R_C(46)$$

where:

$$M = NumberofUAVs$$
$$R_c = Radiusofthedesiredgeographicalarea$$
$$\vec{r_j} = vectorlocationofjthUAVwithinthe2Dplaneofthetargetareaconsideringthecentre$$
$$r_u = maximumcoverageregionof\text{each}UAV\left(asgivenbyequation(42)\right)$$

The first constraint (equation 45) is for prevention of overlapping. The second constraint (equation 46) ensures that UAV do not cover outside the desired area to prevent them from causing interference or transmitting service to non desired area.

### 2.2.5 SYSTEM MODELS BASED ON OTHER METHODS

Base on curiosity and careful study of different works. Other methods for the positioning or placement of UAVs are all fundamentally based on CPT as related to the three methods discussed above. Most of the authors achieved the basis of the CPT by using other optimization techniques like variants of Swarm Intelligence (SI) based and Bio-Inspired (BI) or Non SI optimization algorithms like Black Hole, Particle Swarm, Spiral Optimization, User Association Optimization and Water Cycle Optimization (Alzenad et al., 2017; Shakhatreh et al., 2017; Sallouha et al., 2018; Sun & Masouros, 2018; M et al., 2019; Munaye et al., 2019; Ozturk et al., 2020; Shakhatreh et al., 2021; Zhao et al., 2021)

## 3. DISCUSSION: PROSPECTS, CHALLENGES AND PROCEDURES

### 3.1 Prospects

Careful examination of the specific target terrain is needed for formulation of efficient system models that can capture the air to ground (AtG) transmission modelling, path loss, LOS, NLOS, ground user distribution density and so on. Hence, efficient improvement on the existing model can be established which means numerous research opportunities exist in this area.

Scilab, Scipy and Numpy and other open source numerical analysis applications can handle most of the optimization system models using functions or toolboxes like "karmarkar and optim". Hence, it alleviates the fear of research in UAV trajectory and placement optimization because of scarcity or non availability of famous licenced numerical and optimization applications.

### 3.2 Challenges and Procedures

Different names are giving to the process of deployment in a specific position to provide a certain service including emergency wireless communication service or the service in a remote place out of reach of fixed base station. To mention a view of these terms are positioning, localization, deployment and so on. The major challenges is the accuracy of the on board gps sensor. The UAV must accommodate an effective and sensitive on board gps or add-on that can enhance the effectiveness of all the deployment model. The gps sensor must be effective in identification and segmentation of users to optimally ensure that each Aerial BS has possible maximum user density and coverage radius without ICI.

The following are considerations or assumptions to be made for the development of the model:

1. The Coverage area is assumed to be a circular region of radius R.
2. There are m pieces of Aerial BS to be deployed.
3. All the Aerial BS are assumed to transmit radiate equal power.
4. All the Aerial BS are positioned at the same altitudes, h.
5. A stationary low altitude aerial platform such as quadrotor UAVs were used..

Based on the few reviewed works, below procedure were inferred. It will enhance further work of the author in the area of optimization problem in deployment of UAV.

Step 1: Determination of coverage radius of each UAV in the presence of interference from another UAVs.

Step 2: Derivation of coverage probability of a single UAV.

Step 3: Then develop an efficient deployment strategy for m quantities of UAVs that maximizes the total coverage performance while maximizing the coverage.

Step 4: Developed the deployment optimization system model for the specific problem at hand.

Step 5: Simulate the system model and use effective optimization solver for analysis of effectiveness of the proposed solutions.

## 4.0 CONCLUSION

Different technical literature emphasized apt utilization of UAVs for providing communication link services for different electronic devices. Its services as Aerial BS could be in the area of quick service recovery in case of failure fixed base station (BS), improvement on quality of services by complementing fixed BS and temporary or permanent on demand communication links where fixed BS could not be easily deployed. Multiple deployment of Aerial BSs are usually required. This called for each UAV to be deployed at an optimal position while considering the given bounded region and other UAVs. Hence, the task requires the use of any optimization algorithm that can maximized its relative maximum maximum user density or coverage of maximum number of ground users within the bounded region with minimum inter-cell interference and power consumption. This paper presented overviews of three different variants of Circle Packing Theory (CPT) based system optimization model for optimal placement of Aerial BSs for communication link applications – Basic CPT, LA and KMC methods. UAVs applications in communications are still opened for more researches in the area trajectory and positioning optimizations. Different improvements came as a result solving the problems on non linear objective function, non- convex constraints, path loss consideration and avoidance of inter-cell interference. Therefore, the presented fundamental knowledge should enhance future development of novel system models and optimization algorithms in optimal positioning of multiple UAVs with mentioned at affordable cost to the researchers via mentioned software tools and procedure.

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