Performance Comparison of Heuristic Algorithms for UAV Deployment with Low Power Consumption

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***Abstract*—To minimize power consumption of UAV is one of the big challenges in the UAV deployment. However, it is NP-hard problem due to the pathloss models for Air-to-Ground (A2G) in three-dimensional (3D) area. Therefore many heuristic algorithms are used to solve the UAV deployment. In this paper, we compare the performance of heuristic algorithms for optimal UAV deployment. Among the many heuristic algorithms, we consider Particle Swarm Optimization (PSO), Genetic Algorithm (GA), and Non-hierarchical method which are mostly used for UAV deployment according to each scenario. Performance results show that PSO has better performance than GA in a single UAV case, and Non-hierarchical method has better performance than PSO in multi-UAV case.**

***Index Terms*—UAV, Optimization Theory, Power consumption, Particle Swarm Optimization, Genetic Algorithm**

I. Introduction

Recently, the Unmanned Aerial Vehicles(UAVs) has come into the spotlight as flying mobile base station for providing connectivity and reliability to the ground users or devices. In particular, UAVs can be used in the areas where the network infrastructure is difficult to construct such as the rural area, and the mountainous area or destroyed such as the natural disaster or state of war. A typical example, AT&T's 'Flying COW' provide LTE-connected emergency cellular service in Puerto Rico to connect users, responders, and disaster recovery team [1].

UAV has many advantages to be used as a mobile base station, but it has to overcome some constraints. The power consumption associated with the survival of the UAV is one of the constraints to consider since the UAV is driven by fuel or secondary battery, unlike existing base stations. For this purpose, [2] and [3] are being studied to minimize the power consumption of UAVs. Among them, one of the typical studies is UAV deployment.

However, UAV deployment is NP-hard problem like an existing base station designing problem. Due to the pathloss models for Air-to-Ground (A2G) in three-dimensional (3D) area, the optimal position is impossible to derive from mathematical deduction [4]. Therefore, many studies are using heuristic algorithms to solve this problem. The algorithms used in this paper are Particle Swarm Optimization (PSO), Genetic algorithm (GA), and Non-hierarchical method which are the most often used for UAV deployment [5].

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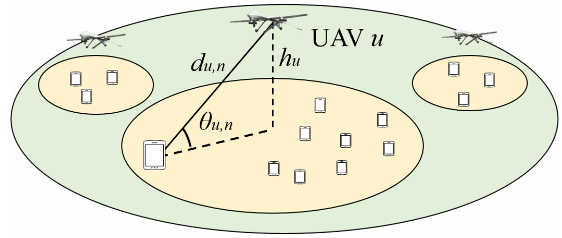

Fig. 1. System Model

The main contribution of this paper is a comparison of the performance of heuristic algorithms for optimal UAV deployment. In particular, we compare the performance of the heuristic algorithms for each scenario based on the number of UAVs and present the convergence speed of reaching the near-optimal solutions as the results. A detailed description for the scenario is given in the next chapter.

II. System Model

Consider a number of ground users, *N*, are located in the suburban area which is supported wireless service by UAVs. *U* is the set of UAVs. We assume that the location of the ground users and the UAVs are fixed. Let h_u be the altitude of UAV *u* ($u \in U$), $d_{u,n}$ and $\theta_{u,n}$ be, respectively, the two-dimensional (2D) distance and the elevation angle between a given UAV *u* and its associated ground user *n* ($n \in N$).

The UAVs must support the service to the ground users within their maximum capacity. Moreover, the ground users received their data to the UAVs in the downlink using the constant bandwidth. C_u is the maximum capacity of a UAV *u*, C_n is the data rate of a ground user *n*, and *B* is the bandwidth. The system model is shown in Fig. 1.

Given this model, we consider two scenarios to compare the performance of the heuristic algorithms for the UAV deployment minimizing UAV power consumption. The **Scenario 1** can be referred to as the single UAV case. In this case, given the optimization model from the power relationship between the UAV and the ground users, we find out the near-optimal position of a UAV using PSO and GA. The **Scenario 2** is referred to the multi-UAV case. In this case, we use PSO and Non-hierarchical method to find out the near optimal position of the UAVs.

A. A2G Pathloss Model

For designing the optimization model, we use the pathloss model proposed in [6]. The LoS probability which is provided by International Telecommunication Union (ITU-R) and [7] is given by [6]:

$$P(LoS, \theta) = \frac{1}{1 + a \times \exp\{-b(\theta_{u,n} - a)\}}, \tag{1}$$

where a and b are the S-curve parameters which determined by environment, and $\theta_{u,n}$ is the elevation angle which can be expressed as follow:

$$\theta_{u,n} = arctan\left(\frac{h_u}{r_{u,n}}\right). \tag{2}$$

The A2G pathloss can be derived:

$$PL_{u,n} = \frac{L}{1 + a \times \exp\{-b(\theta_{u,n} - a)\}} + 20log\left(\frac{4\pi f d_{u,n}}{C}\right) + \eta_{NLoS}. \tag{3}$$

L is the subtraction η_{NLoS} from η_{LoS} which are average additional loss for LoS and NLoS propagation groups, f is the central frequency, and C is the speed of light.

III. Effecient Deployment of UAV

A. Optimization Model

Consider a UAV u and a ground user n is in a suburban area. The received data rate for user n is given by:

$$C_n = Blog_2\left\{1 + \frac{P_{t,u}}{PL_{u,n}(N_g + I_n)}\right\}. \tag{4}$$

$P_{t,u}$ is the transmit power of UAV u, N_g is the noise, and I_n is the interference from all UAVs except UAV u. If the ground users are served in the coverage of UAV u, then the required minimum power to satisfy the received data rate for each ground users is given by:

$$P_{t,u} = \sum_{n \in 2\pi r_{u,n}^2} 2^{C_n/B} \times (N_g + I_n) \times PL_{u,n}. \tag{5}$$

To find out the optimal position of the UAVs, we assume that the altitude of the UAVs is the same. Therefore, our optimization model can be formulated to find the X and Y coordinates of the UAVs as:

$$\{\boldsymbol{X}^*, \boldsymbol{Y}^*\} = argmin \sum_{u \in U} P_{t,u}. \tag{6}$$

$$s.t. \quad x_u \in \boldsymbol{X}^*, y_u \in \boldsymbol{Y}^*, \quad u = 1, ..., U \tag{7}$$

$$\sum_{u=1}^{U} \sum_{n \in 2\pi r_{u,n}^2} un = N, \tag{8}$$

$$\sum_{n \in 2\pi r_{u,n}^2} C_n < C_u. \tag{9}$$

B. Heuristic Algorithm

In mathematical optimization, a heuristic algorithm is a method which can find a solution quickly and efficiently when the traditional methods fail to find it. The objective of a heuristic algorithm is to find the best solution in a reasonable time, not the exact optimal solution. The UAV deployment is the NP-hard problem due to the vary pathloss model in the area. To solve this problem, some of the heuristic algorithms such as PSO, GA, Non-hierarchical method, are employed. A brief description of each algorithm follows [3][4].

- PSO algorithm was proposed by Eberhart and Kennedy, inspired by the swarming behavior of birds. PSO consists of some individual particles which have the position and the velocity in the given search space. The particle's position and velocity are updated in each iteration and find the local best value and the global best value.
- GA is a search algorithm inspired by the process of natural evolution. This algorithm is typically used to generate useful solutions to optimization and search problems. GA derive solutions to optimization problems using techniques such as inheritance, mutation, selection, and crossover.
- Non-hierarchical method is a method of optimizing a given criterion to divide the values to be observed into several clusters. The process of the algorithm is to measure the degree of similarity between observed values, perform clustering, and then repeat the process of adjusting the cluster center.

IV. Performance Analysis

To compare the performance of the heuristic algorithms, we perform the simulation using MATLAB. We compare PSO with GA in **Scenario 1** and compare PSO algorithm with Non-hierarchical method in **Scenario 2**. The performance analysis environment refers to [2]. We consider a total number of 50 ground users in Scenario 1 and a total number of 500 ground users in Scenario 2 which are randomly distributed on the system model of size 1 Km $\times$ 1 Km. The other parameters are list in Table 1.

A. Results for Scenario 1

Fig. 2. show the convergence speed of PSO and GA. For using PSO, we consider that the number of particle populations sets to 100, the inertia weight w sets to 0.9, and the weight of

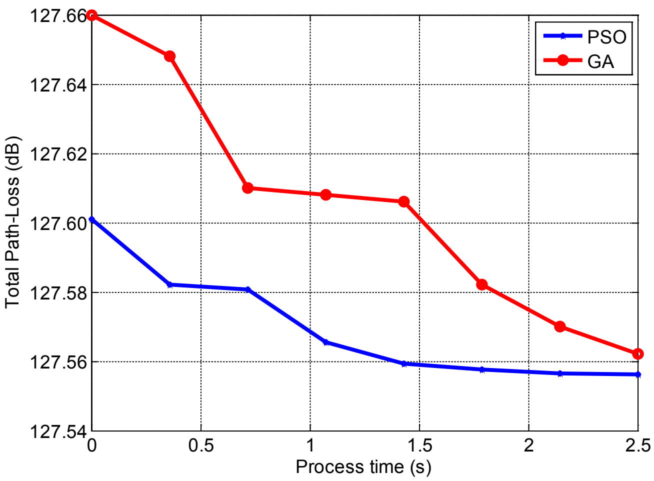

Fig. 2. Convergence speed, PSO vs. GA

TABLE I
PERFORMANCE ANALYSIS ENVIRONMENT

Parameter	Values
a, b	9.61, 0.1
c	$3 \times 10^8 m/s$
$\eta_L oS, \eta_N LoS$	1 dB, 20 dB
f, B	2 GHz, 1 MHz
N_g	-120 dBm
C_u	1 Gbps
h_u	1 km
C_g	1 Mbps (Scenario 1) 1 Mbps, 10 Mbps, 100 Mbps, (Scenario 2)

local information, C_l, and the weight of global information, C_g, set to 1.9 and 2.1, respectively. In the GA, generation sets to 250, and the population size sets to 40, and other parameters such as crossover, mutation set default value of the MATLAB OPTIMIZATION TOOLBOX. In Fig. 2, the convergence speed of PSO is faster than that of GA, and the near optimum value of PSO is lower than that of GA. GA requires the optimization process to be applied at least 10 times to find a valid value of the UAV position in this scenario. The particle movement of the PSO can usually allow faster convergence and more variety/diversity than GA. However, PSO is more likely to stay in local optimum than GA.

B. Results for Scenario 2

Fig. 3. show the convergence speed of PSO and Non-hierarchical method. The parameters of PSO are the same as in Scenario 1. In the Non-hierarchical method, the number of clusters sets three which considers the capacity of a UAV and the data rate of the ground users. Since the many particles of PSO exchange the values which are derived from the cost function, the convergence speed of the Non-hierarchical method is faster than that of PSO, and the near optimum value of Non-hierarchical method is lower than that of PSO.

As the number of particles increases, PSO has a longer iteration times than that of Non-hierarchical method.

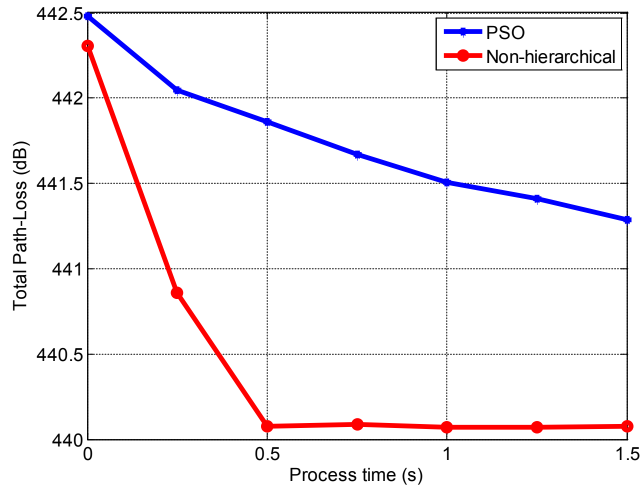

Fig. 3. Convergence speed, PSO vs. Non-hierarchical

V. CONCLUSION

In this paper, we compare the performance of heuristic algorithms for Optimal UAV deployment. For these performance results, we can confirm the heuristic algorithm which can be used in one or multi-UAVs scenario. In the future, we will consider case of the UAV or user movement scenario, and use the state-of-the-art technology, Deep learning, for performance evaluation.

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