Efficient deployment of UAVs to achieve hole free coverage

Ishan Neogi[1], Suraj Kumar Singh[2], Suryansh Sharma[3], Shailendra Sharma[3]
[1] D.A.V. Public School Gurugram
[2] The Maurya School
[3] Amity International School Ghaziabad
[3] Independent Researcher

Abstract – One of the most important applications of the UAVs like drones is surveillance of a particular region. A hole in a surveillance region may lead to inefficient coverage. It is imperative to ensure proper deployment of UAVs in a region and ensure a hole free coverage. In this paper, we propose a novel election algorithm that provides a hole free coverage and also ensure speedy movement of UAV nodes towards the coverage hole. The proposed algorithm outperforms some of the famous algorithms of the past by 12 % and 45 % respectively.

Keywords – UAV, deployment, drone, UAV neighbours.

I.. Introduction.

Unmanned aerial vehicle or drone is an aircraft which does not have any human pilot onboard. UAV can be operated in various ways including by remote control human operator or autonomously using onboard computers. UAVs are being widely used in commercial, military, agricultural and other applications nowadays. A common application of UAV is to search a specific area for some sort of targets. Targets vary from application to application. One example is finding the debris of missing airplane. Widespread research on its trajectory design, autonomous and reliable communication among UAVs of a group is being done in recent times. Moreover, optimizing various objectives such as, mission time, coverage, number of UAVs needed etc, are also being heavily investigated for drones by the researchers. As small and mini drones have become widely spread a common scenario is to deploy a group of UAVs to accomplish a mission instead of a single one. For different problems different strategies and algorithms are used to meet the objective specific to those problems. However all these deployment is done keeping all the UAVs in a fixed height. Here, it is assumed that targets will be detected if somehow it is scanned at the specified height. The probability of detecting a target by an UAV largely depends on the height of the UAV. The more the height of the UAV the more the distance from target on ground which results increase chance of failure. Moreover, the required height varies for different environmental and other conditions. Land, ocean, forest, urban block etc., affect differently. The weather condition such as rain, fog, sunny, storm all these impose different effect. Posture of the object and some other aspects are also responsible for the accuracy of the search. As a result it is necessary to deploy UAVs in variable heights to ensure better dependability of search result. To the best of our knowledge deploying UAVs of a group in different heights has not been done before.

Figure 1 (a) – A UAV operating in a deployment region [5].

Unmanned Aerial Vehicles (UAVs) have gained popularity in many industries due to their vast potential applications, such as survey, search and rescue, agriculture, or forestry [1]. In the last decade, a significant amount of research was carried on using and processing the information supplied by a single UAV. However, the reduced costs of commercial-grade UAV facilitates usage of interconnect multiple UAVs in an adaptive and autonomous acting system [2]. Such a UAV swarm is capable of accomplishing tasks which one UAV either fulfils with difficulty, such as accurate determination of the location for an object, or fails to accomplish altogether, such as mapping of inaccessible caves or dense rain forest, assessment of real-time environmental processes, or wildlife monitoring. Furthermore, compared to a one UAV, a UAV swarm is able not only to solve more tasks, but also to reduce the time of executing various activities and to increase the quality of collected data. Additionally, if the task requires navigational autonomy within an unknown or difficult environment, a UAV swarm offers robustness through redundancy and self-organization, which cannot be achieved by deploying one UAV.

A particular case of a demanding flying environment is represented by the interior of a forest. Data collection using sensors carried above the forest canopy was executed for more than one century [3-9], but accurate resource assessment still eludes foresters, as little useful information can be obtained from sources located outside forest [10-14]. The limited success in describing forest from afar is induced by the lack of algorithms that accurately classify the information remotely sensed acquired in elementary components (e.g., trees, shrubs, stem).

A UAV swarm can significantly increase the productivity and accuracy of data describing the forest as a set of three dimensional objects, each having multiple attributes attached (such as taper, infestation with damaging biotic agents, or thermal radiance) [15-20]. Each UAV maintains communication capabilities with neighbouring UAVs which are in its transmission range. The UAVs adapt to the unknown environment, circumvent obstacles, and map the forest with a variety of sensors. Afterwards, the swarm leader UAV transmits the collected and aggregated data to the base station or operator

for data analysis and advanced post processing. However, the advantages promised by an autonomous UAV
swarm face challenges that come with the efficient swarm formation and communication preservation. The set of UAVs should exhibit a swarm-like behaviour that provides an adaptive and reliable network structure while fulfilling the required tasks for assessment of environment (e.g., three dimensions, amount of light, or spatial variation of humidity inside the forest) [6], [7].

II. RELATED WORK AND MOTIVATION BEHIND OUR WORK

The study presented in [1] proposes a multi-objective optimization strategy for a group of UAVs where coverage is maximized, the number of UAVs required is minimized, and searching time is minimized. Here the height of all UAVs is assumed to be constant and thus the optimization problem is reduced to a 2D problem. Besides the study presented in [2] focuses on how a low lying UAV can plan its motion keeping in mind specific goals, such as avoiding obstacles and looking for acceptable landing sites while performing continuous surveillance. Additionally the study in [3] investigates the problem of minimum time coverage of ground areas using a group of UAVs equipped with image sensors. In addition the study in [4] proposes a model driven framework for system design and on-the-fly path (re)planning strategy for UAVs. Nonetheless, the study in [5] presents real UAVs. To the best of our knowledge all of these studies focus on deploying UAVs at fixed flying heights. Some works have been found where height optimization is done but those are totally for different type of problems, not for searching a certain area. Like, in [6] an optimal path between two waypoints in the target 3D space is developed under various constraints. Whereas in [7] UAVs are used as flying base stations where total transmit power is minimized while meeting users rate requirements. Coming back to our problem of covering the entire region with minimum UAVs flying at a optimum height is implemented in this paper. This happens due to various factors such as weather condition, terrain type etc. As these conditions vary over different parts of territory under reconnaissance, it is of utmost significance to deploy different UAVs at different flying locations over different parts to render a dependable search. However, investigating such a deployment is yet to be focused in the literature. Therefore, in this paper, we investigate a methodology for such deployment of UAVs.

III. Proposed Algorithm.

A. Problem Description

The UAVs are to be deployed forming a mesh network to provide wireless coverage to ground users. The users are mobile which implies that there is non uniform densities of users at different sub regions in the given region. As there is a limitation on the number of UAVs, the entire region can never be covered, hence, not all of the users will get served. The aim is to cover as much area - in essence maximum users - as possible, but keeping in mind the limited numbers of UAVs available.

B. Assumptions

To focus on solving the problem in hand, we make various realistic assumptions as listed below:

- All the UAVs are homogeneous in nature, i.e. each has the same capability and covers the same area as its peers.
- There is a fixed number of UAVs deployed in the region.
- Initially, all the UAVs attain positions following Delaunay triangulation, forming equilateral triangles.
- Each UAV knows its current position (coordinates) and has a neighbor table.
- Each UAV makes sure that it has at least one neighbor so that it remains in the mesh network.

C. Implementation

- UAVs often operate in a network structure where intra network communication plays an important part.
- For most applications of UAVs, we require adequate coverage of a surveillance region in such a way that entire deployment area is covered by ample UAV nodes.
- We propose a novel election algorithm for efficient deployment of the UAV nodes in a deployment region.
- In our algorithm, entire deployment region is divided into several virtual cells where each cell may contain one of many UAV nodes.
- For efficient deployment of UAVs in a surveillance region each cell must contain at least one UAV node.
- If a cell is empty it sends a signal to all the nearby cells about its vacancy.
- The UAV which is closest to the elects itself to fill the vacant cell and moves towards the empty cell with a kinetic velocity v.
- For movement towards the cell it uses shortest path algorithm Ant colony optimization.
- In this way election algorithm is executed for the entire region and all the deployment area is properly covered by a UAVs.
- Proper deployment not only ensures full coverage but also gives user a hole free surveillance application of UAVs.

IV. Results. In this section, we conduct simulations to evaluate the performances of our proposed deployment algorithms. All the values reported later are collected from the average of 1000 runs for each algorithm. All parameters of UAVs are randomly generated. The length of target interval is set to be 20 kilometers, while the maximum flying speed and maximum coverage radius are set to be 50 kilometers per hour and 2 kilometers, unless otherwise stated.Results of the proposed algorithm are obtained using the configuration of the hardware core-i5 processor with 4GB RAMS..

A UAV deployment between two static nodes is shown in figure 1 (b).

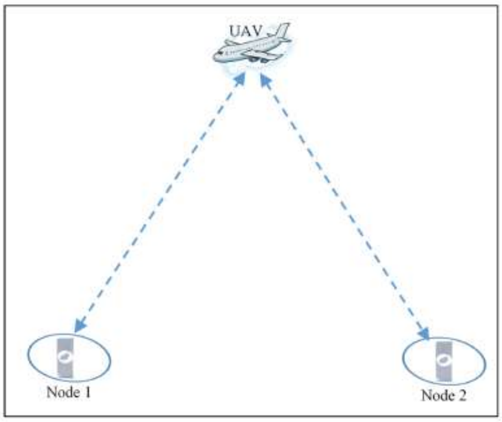

Figure 1 (b) – UAV deployment between 2 nodes.

An initial deployment of 100 UAVs is shown in figure 1 (c).

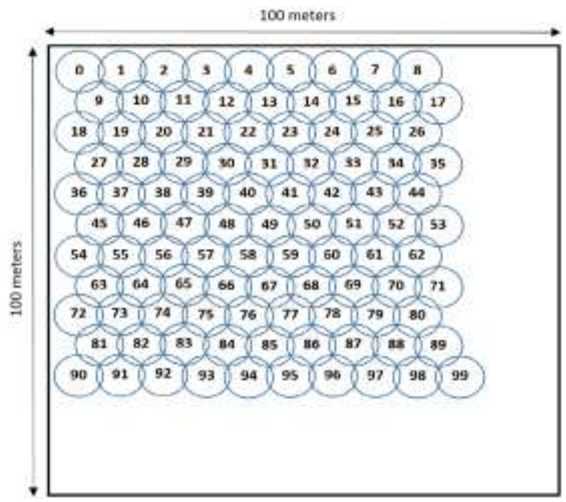

Figure 1 (c) – Initial deployment of 100 UAVs

Figure 2 shows the percentage area covered by proposed algorithm in comparison to the past algorithm PIA and when there is simple deployment used.

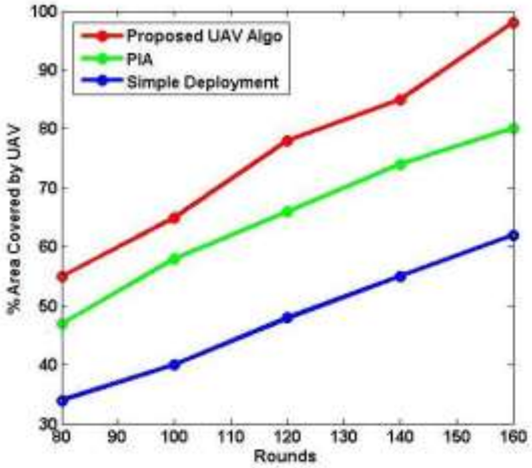

Figure 2 – Area covered by the proposed algorithm

Figure 3 shows the energy consumed by a UAV node in moving from a specific cell to the cell where there is a coverage hole.

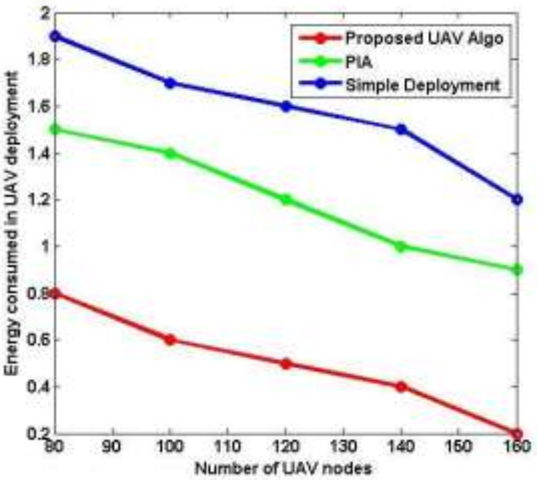

Figure 3 – Energy consumed by the UAV node in filling the coverage hole

Figure 4 shows the speed in milliseconds by which a UAV moves to the coverage hole. It is evident from the figure that proposed work performs best in terms of coverage speed as compared to the past algorithms.

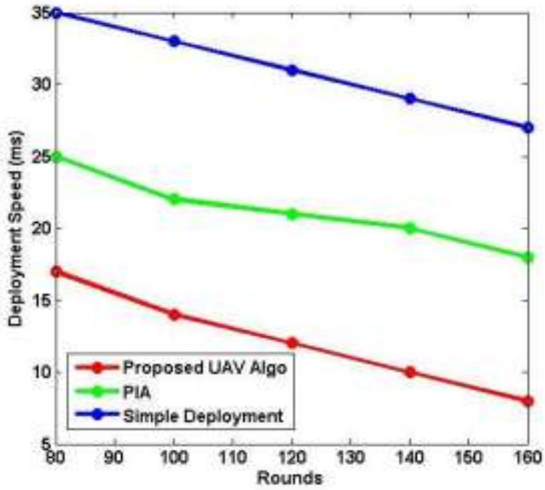

Figure 4 – Speed of filling the coverage hole

Figure 5 shows the lifetime of a UAV node after the movement from its original location to the vacant cell is completed.

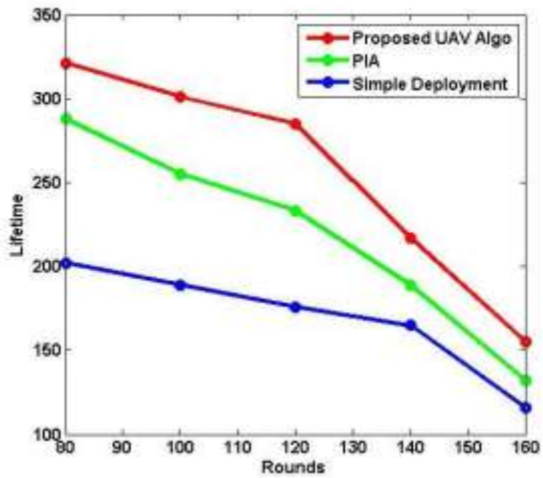

Figure 5 – Average lifetime of a UAV in rounds.

It is evident from all the figures that the proposed work works best in all the cases.

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