Feedback based Mobility Control Algorithm for Maximizing Node Coverage by Drone Base Stations

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Abstract—Drone base stations (DBSs) have recently gained wide popularity as a possible solution to provide wireless connectivity in a variety of scenarios, for example, in inaccessible terrains such as connectivity over vast areas of a water body or in rural areas where the physical deployment of base stations is not feasible at the moment, also in the case of terrestrial infrastructure failure where DBSs can be rapidly deployed to re-establish communication channel. In this paper we propose an algorithm for controlling the motion of the DBSs which maximizes the number of DBS to mobile ground node connections. The overlap extent between the drones is limited to reduce the count of redundant connections. The overall approach aims at minimizing the number of drones required to be deployed in a given region by maximizing connectivity per drone.

Index Terms—Drone Base Station, UAV, mobility, macro hotspot, deployment

I. INTRODUCTION

Unmanned Aerial Vehicles are widely used for reconnaissance operations [1] in disaster struck regions. In such cases, emergency base stations are required to serve as temporary replacement of the damaged communication infrastructure. A prospective solution for establishing a wireless recovery network in disaster affected zones is by utilizing airborne base stations. With developments in communication technology, providing adequate network coverage in rural areas becomes a topic of key interest as most of the areas in developing nations are rural and do not have proper network coverage. Communication over water bodies or dense forests is not possible due to the non feasibility of deployment of terrestrial base stations. This is the motivation for our work, that is, to provide an efficient, scalable and robust solution for the deployment of Drone Base Stations (DBSs) as a means to provide wireless connectivity in inaccessible terrains. The word drone is used synonymously with UAV throughout the paper.

The utility of UAVs is undoubtedly high. This is established by the fact that the Tech Giants are using drones for their upcoming technologies. Amazon is using drones [2] to deliver packages to its customers under the service name Amazon Prime Air. Facebook’s Aquila [3] [4] is an experimental drone to function as an atmospheric satellite and provide internet access to remote areas. The drones are solar powered to account for the high energy requirement. Similar to Facebook’s aim for Aquila, Google is developing its Project Loon [3] [5] [6] which aims at providing high speed internet to rural and remote areas with the help of a network of balloons equipped with solar-powered transceivers.

Fotouhi et al. [7] proposed a mobility control algorithm for the drone base stations. The algorithm tries to decrease the distance between the ground nodes and DBS in order to increase the probably of a line of sight connection. Lei Wang et al. [8] find the optimum height of the DBS to minimize the average transmission power to save the precious resource of the drone which is energy. The authors in [9] assumed the DBSs transmits at full power and formulated the 3D DBSs placement problem as a quadratically-constrained mixed integer non-linear problem. Kalantari et al. [10], developed a heuristic algorithm based on particle swarm optimization. The algorithm suboptimally finds the minimum number of DBSs and their locations to serve a particular region. Mozaffari et al. [11] optimized the DBS altitude that results in maximum coverage region and minimum transmit power for two cases, a single DBS and two DBSs. In [12], they developed a method to deploy multiple DBSs based on circle packing.

In this paper we propose a feedback-based mobility control algorithm for drone base stations to maximize connectivity with the mobile ground nodes exhibiting random walk. The change in the count of ground nodes a DBS is connected to is the feedback in our algorithm. The drone alters its position so as to maintain connectivity if it falls below a certain threshold. We define performance metrics based on the number of ground nodes a DBS serves. These performance metrics are compared with the random walk mobility of DBSs.
The paper is organized as follows. In Section 2, we discuss the equations governing the functions which are used in the algorithm described in Section 3 followed by Results and Analysis in Section 4. Section 5 presents the concluding remarks and some possible future works.

II. SYSTEM MODEL

In this work, the macro hotspot scenario has been considered, similar to [7], in which both the drones and the ground nodes are mobile. Due to the mobility of the ground nodes, we can never estimate the positions of all the ground nodes which makes the problem even more realistic, in which we do not have a map depicting the density of ground nodes spread out in the considered region.

![Top-view of the system environment](image)

**Fig. 2: Top-view of the system environment**

We assume that $n_G$ users (ground nodes) are uniformly distributed in the Region of Interest ($L \times L$). The drones have been placed at a fixed altitude above the ground and are allowed movement only in the two dimensional plane. Each mobile node connects to its nearest drone base station. Figure 2 shows the topview of the DBS and user setup. Each DBS has been assumed to have a coverage area or a detection region equivalent to circular geographical region having radius $R$.

| Notation | Description |
|----------|-------------|
| $n_D$    | Number of DBSs deployed |
| $n_G$    | Number of ground nodes |
| $L$      | Side length of the area of interest |
| $R$      | Radius of the DBS connectivity range |
| $X, \bar{Y}$ | Centroid of all the groundnodes connected to a DBS |
| $w_x, w_y$ | Destination coordinates for a DBS |
| $R_o$    | Radius set for limiting overlap |
| $M$      | Instantaneous connectivity |
| $M'$     | Previous connectivity |
| $M_{max}$ | Personal best Connectivity |
| $\phi$   | Threshold |

**TABLE I: Nomenclature**

Simulations have been performed and results have been obtained considering that the mobile users or nodes are in a state of random walk mobility. The drone changes its position depending on centroids of the connected nodes and the change in the number of nodes it is connected to in the current state w.r.t. the previous state (feedback) and the threshold.

III. ALGORITHM

The drones first maximize the distance between them, if its falls below minimum value of $R_o$, by each of them moving away through the line of sight. For a pair of drones with coordinates $(x_i, y_i)$ and $(x_j, y_j)$ we first find the centroid $(c_x, c_y)$ such that $c_x = (x_i + x_j)/2$, $c_y = (y_i + y_j)/2$ and then shift both drones a distance $R_o/2$ away from the centroid.

\[
s_j \leftarrow c_s + \frac{s_j - c_s}{\sqrt{(x_j - c_x)^2 + (y_j - c_y)^2}} R_o/2; \quad s \in \{x, y\} \tag{1}\]

Then the drones check how many ground nodes they are serving instantaneously. For each drone, we have a set $C = \{g_1, g_2, g_3, \ldots g_M\}$ of ground nodes $g_i(x_i, y_i)$ which fall within its communication range $R$. Based on the $xy$ coordinates of all the ground nodes connected to a drone base station, it calculates the centroid $(\bar{X}, \bar{Y})$ as

\[
\bar{X} = \frac{\sum_{i=1}^{M} x_i}{M}; \quad \bar{Y} = \frac{\sum_{i=1}^{M} y_i}{M}; \quad g_i(x_i, y_i) \in C, \quad |C| = M \tag{2}\]

and then calculates the destination $(w_x, w_y)$ as

\[
w_x = \bar{X} + (-1)^p R/2; \quad w_y = \bar{Y} + (-1)^p R/2; \tag{3}\]

where $R$ is the connectivity range of each drone and $p \in \{0,1\}$ having uniform probability of occurrence. We basically try to increase the distance between the drone and the centroid of connected ground nodes so that it may get connected to ground notes lying outside. This kind of approach is helpful because in order to maximize connections, we try to retain the current number of connections and then by maintaining a safe distance so as not to lose connection, we fetch more on the way.

After this, the drone proceeds to move towards its destination and after a certain time step performs a check. The number of ground nodes being served $(M)$ is counted and checked against the pervious value $(M')$ and threshold $\phi$. If $M'$ exceeds $M$ and the threshold or when $M$ exceeds $M'$ by a defined vale called $Loss$ then the drone base station reverts its position.

IV. RESULTS AND ANALYSIS

The main focus of this algorithm is the maximization of connectivity $(M)$ of each DBS. To show the performance of our algorithm as claimed, we plot connectivity in figure 3. The solid black line represents the mean connectivity of all
Algorithm 1 Drone Mobility Algorithm

1: Start
2: Minimize Overlap between drones
3: Find Connections
4: Set Centroid
5: Set Destination
6: Set Velocity
7: Update Position
8: if $M' > \phi$ & $M < M'$ then
9:   Revert Position
10:  Find Connections
11:  if $M < M_{max}$ then
12:    $M_{max} = \max(M, \phi)$
13:    end if
14:  else
15:   if $M < M' - Loss$ then
16:     Revert Position
17:   end if
18:  end if
19: Go to Step 2

Fig. 3: Connectivity ($M$) of all DBS plotted against time. (Simulation Parameters: $n_D = 15$, $n_G = 10^4$, $T = 10^3 s$, $\phi = 25$)

Figure 4 is a different visual representation of the data present in figure 3. The bar graphs depict the average connectivity, the error bar show the minimum and maximum values of M and the star indicates the value of M for the drone at completion time. The deep crest around $t = 400s$ highlights the feedback mechanism present in the algorithm based on the values of $M$ and $M'$.

A metric, called the Average Connectivity $\bar{M}$ is defined as

$$\bar{M} = \frac{1}{T} \int_{t=0}^{T} \sum_{i=0}^{n_D} M_i(t)$$  

(4)

Since the simulation is done in time steps, the integral can be converted to summation.

In figure 5 the plot of $\bar{M}$ vs. $n_D$ is shown. The error bar depicts the maximum and minimum connectivity values and the star marks the value of average connectivity towards completion of the simulation. The number of users served increases linearly with linear increase in $n_D$. 

Fig. 4: The Various values of connectivity ($M$) plotted for different drones. (Simulation Parameters: $n_D = 15$, $n_G = 10^4$, $T = 10^3 s$, $\phi = 25$)

Fig. 5: Average connectivity ($\bar{M}$) plotted against the number of drones ($n_D$). (Simulation Parameters: $n_G = 10^4$, $T = 10^3 s$, $\phi = 25$)
A. Comparison with Random Walk

In this part of the results, we show how the performance of the proposed mobility algorithm is superior to random walk motion of DBSs.

\[ n_G = 10^4, T = 10^3s, \phi = 25 \]

In figure 6, the scatter plot is the simulated data and the solid lines are the polynomial fits of the scattered plots. It is clearly evident that over the course of time, the drones are successful in maximizing the number of connections but the random walk mobility provides nearly constant connectivity throughout.

Fig. 6: Mean connectivity vs. time. (Simulation Parameters: \( n_G = 10^4, T = 10^3s, \phi = 25 \))

In figure 7, the proposed mobility algorithm outperforms random walk and the difference in performance increases with increase in number of drones.

Fig. 7: Average connectivity (\( \bar{M} \)) plotted against the number of drones (\( n_D \)). (Simulation Parameters: \( n_G = 10^4, T = 10^3s, \phi = 25 \))

V. CONCLUSIONS

In this paper, we presented a drone mobility algorithm which tends to maximize the number of ground nodes it serves. The superiority of our algorithm over random walk of drones is established in section IV. When implemented, it increases the total number of users served for a scenario thereby minimizing the amount of drones needed which in simple words is minimizing the resources required. The mobility control algorithm also provides a comparatively stable connection by dividing the region into exclusive coverage zone for each drone. For future work we plan to study the effect of threshold \( \phi \) value on connectivity \( \bar{M} \) and find the optimum value of \( \phi \) as a function of number of ground nodes and \( L \). In this paper, we considered the ground nodes to be uniformly distributed in the confined region, for extension we plan to distribute the ground nodes as dynamic clusters and test our proposed algorithm in that case.

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