Evolving Potential Field Parameters For Deploying UAV-based Two-hop Wireless Mesh Networks

Rahul Dubey
University of Nevada Reno
rdubey018@nevada.unr.edu

Sushil J. Louis
University of Nevada Reno
sushil@unr.edu

ABSTRACT

We attack the problem of dynamic UAV-based ad-hoc mesh network deployment to find and connect people in an area of interest. Genetic algorithms tune the parameters of potential fields that control UAV movement in order to optimize people coverage and network longevity. We extend earlier work that assumed one-hop communication between UAVs to the more realistic two-hop case and find significant increase in coverage and network longevity. Experimental results show that enabling two-hop communications between UAVs improves the performance on average between 4% to 32.19%.

CCS CONCEPTS

• **Computing methodologies** → **Genetic Algorithms**;

KEYWORDS

UAV Network, Distributed Control

ACM Reference Format:

Rahul Dubey and Sushil J. Louis. 2021. Evolving Potential Field Parameters For Deploying UAV-based Two-hop Wireless Mesh Networks. In *2021 Genetic and Evolutionary Computation Conference Companion (GECCO '21 Companion), July 10–14, 2021, Lille, France.* ACM, New York, NY, USA, 2 pages. https://doi.org/10.1145/3449726.3459561

1 INTRODUCTION

Unmanned Aerial Vehicles (UAVs) have found myriad uses as costs decrease and capabilities increase [2]. In this work, we use UAVs to serve as wireless base stations in an UAV-based ad-hoc wireless mesh network. We focus on the deployment of such UAV base stations in unknown infrastructure-poor environments. The network deployment problem can be formulated as a single objective optimization problem to maximize a linear combination of bandwidth served and longevity of a deployed network. Drawing from Dubey's Evolutionary Adaptive Network deployment algorithm (EANet), which uses potential fields to control UAV deployment, we use a set of Potential Fields (PFs) to govern the movement of UAVs and use Genetic Algorithms (GA) to tune PF parameters to maximize bandwidth served and network longevity [1]. We enable two-hop communication among neighboring UAVs, increasing the information available for decision making, and show that two-hop communications leads to better performance than one-hop communication. Genetic algorithms make good potential field parameter tuners since potential fields of the form cd^e, where c and e are a coefficient and exponent and d is distance, can be highly non-linear. We specify and tune six potential fields based on distance, user bandwidth requirements, and command center (CC) location using a highly elitist genetic algorithm. Experiments on a variety of scenarios show that with two-hop communications, the proposed Modified EANet (or MEANet) performs statistically significantly better than UAVs with one-hop communication (EANet).

GECCO '21 Companion, July 10–14, 2021, Lille, France

ACM ISBN 978-1-4503-8351-6/21/07.
https://doi.org/10.1145/3449726.3459561

2 METHODOLOGY

We modified EANet [1] by enabling two hop communication. We run algorithm 1 to adapt to the user distribution in a given area of interest (AOI) to compute and return a fitness. A set of potential fields specified by the genetic algorithm to control the movement of UAVs and simulation runs for a number of time steps ($MaxTimeSteps$) equal to 1500. The difference from prior work on EANet is in lines 8 and 9 of the algorithm 1. Line 8 `FindLinkState` decides whether a UAV is part of a permanent link in the deployed wireless mesh network or not. A UAV is part of a permanent link if there is only one link available from the command center to other UAVs through the UAV. If a UAV is part of a permanent link then the UAV maintains its position in the network. In line 9 `FindActivePotentials`, identifies the potential fields experienced by a UAV considering two hop neighbors communication.

$$\vec{PF^k_{uav}} = \vec{PF_{bw}} + \sum_{i=1}^{h}(\vec{PF_{ibw}} + \vec{PF_{id}}) + \vec{PF_{ac}} \tag{1}$$

In equation 1 calculates a direction for each UAV to move based on potential fields. Here h refers to hop count and in this paper $h = 2$ for two hop inter UAV communications. The first term in this equation, $\vec{PF_{bw}}$, specifies an attractive potential field experienced by UAVs based on users bandwidth requirement. This field attracts UAVs towards high density bandwidth demand within the AOI. $\vec{PF_{ibw}}$ specifies attractive potential fields based on bandwidth served by i^{th} hop neighbors and $\vec{PF_{id}}$ refers to repulsive potential fields based on distance to i^{th} hop neighbors. Finally, the command center attracts UAVs in order for the mesh network to be able to connect to the CC which is assumed to be connected to the internet. A potential field specified by PF_{ac} that *only* acts on UAVs which are not serving any users, takes care of this requirement.

3 RESULTS AND CONCLUSION

In this section, we compare our modified approach, MEANet, to the earlier approach in [1]. To facilitate direct comparisons, we kept

Algorithm 1: Modified EANet and fitness computation

```
Input  : Initial position of UAVs, AOI, Candidate Solution
Output : fitness
fitness = 0;
MaxScenarios = 4;
for scenario in MaxScenarios do
    timeSteps = 0;
    while timeSteps<MaxTimeSteps do
        AssociateUsers(scenario);
        FindNeighbors();
        FindLinkState();
        FindActivePotentials();
        Headings = ComputePotentialFields();
        MoveAll(Headings);
        timeSteps++;
    end
    bwCoverage = FindBQCoverage();
    AUs = FindActiveUAVs();
    fitness += bwCoverage / MaxBW + AUs / MaxUAV;
end
fitness = fitness / MaxScenarios;
return(fitness);
```

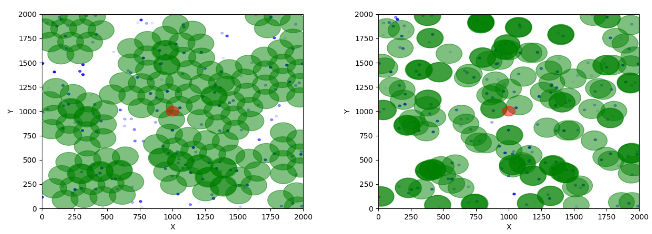

Figure 1: Network deployment with (a) one hop and (b) two hop communication. The red circle represents the CC, blue dots user's location, and green circle is UAV's coverage.

all experimental settings and parameters the same as in [1]. Figure 1 show deployment of UAVs considering one-hop and two-hop UAV-to-UAV communication on one specific exemplar scenario. The figure shows that with one hop communication (a), several users do not obtain coverage and UAVs remain over areas without users; wasting their capacity and reducing network longevity. Networks deployed using our modified approach, MEANet, produce better results compared to EANet (one-hop) deployed networks. We compared the fitness obtained on four training scenarios with one-hop and two hop UAVs communication in Table 1 with 156, 117, and 78 UAVs and 200, 150, 100, and 50 users. We thus compare a total of $3 \times 4 \times 4 = 48$ different combination of UAVs, users, and scenarios. Table 1 shows that fitness obtained with two hop communication was better in all 48 combinations of UAVs, users, and different scenarios. Table 1 also shows that two hop communication performed better on 95% (34/36) combinations of UAVs, users, and testing scenarios. Results show that our modification improved the performance on average between 4% to 32.19% on training and testing scenarios. Additionally, since with sufficient numbers of UAVs (156) we get very close to the optimal fitness of 2, we believe that going to 3, 4 or higher hop communications will not significantly improve coverage performance.

Table 1: Comparing fitness between one hop and two hop network deployment.

User	Hop	Tr_1	Tr_2	Tr_3	Tr_4	Te_1	Te_2	Te_3
156 UAVs								
200	1	1.69	1.56	1.59	1.71	1.69	1.71	1.64
200	2	**1.93**	**1.95**	**1.97**	**1.94**	**1.97**	**1.97**	**1.94**
150	1	1.58	1.44	1.53	1.62	1.61	1.69	1.54
150	2	**1.97**	**1.96**	**1.95**	**1.93**	**1.98**	**1.99**	**1.97**
100	1	1.58	1.29	1.39	1.55	1.53	1.56	1.48
100	2	**1.84**	**1.98**	**1.93**	**1.98**	**1.99**	**1.76**	**1.98**
50	1	1.23	1.20	1.29	1.38	1.33	1.35	1.39
50	2	**1.32**	**1.92**	**1.29**	**1.64**	**1.96**	**1.87**	**1.91**
117 UAVs								
200	1	1.52	1.53	1.61	1.62	1.80	1.72	1.63
200	2	**1.64**	**1.88**	**1.90**	**1.84**	**1.97**	**1.83**	**1.92**
150	1	1.52	1.52	1.62	1.71	1.73	1.71	1.66
150	2	**1.69**	**1.88**	**1.80**	**1.91**	**1.98**	**1.84**	**1.96**
100	1	1.42	1.33	1.48	1.57	1.67	1.60	1.58
100	2	**1.78**	**1.86**	**1.78**	**1.91**	**2**	**1.84**	**2**
50	1	1.22	1.27	1.36	1.25	1.47	1.34	1.43
50	2	**1.51**	**1.77**	**1.85**	**1.60**	**1.59**	**1.56**	**1.97**
78 UAVs								
200	1	1.47	1.25	0.98	1.57	1.74	**1.67**	1.75
200	2	**1.65**	**1.53**	**1.59**	**1.69**	**1.91**	1.65	**1.83**
150	1	1.36	1.38	0.93	1.60	1.83	**1.67**	1.72
150	2	**1.63**	**1.66**	**1.64**	**1.66**	**1.9**	1.64	**1.86**
100	1	1.24	1.31	1.50	1.58	1.71	1.55	1.72
100	2	**1.61**	**1.49**	**1.66**	**1.78**	**1.91**	**1.59**	**1.91**
50	1	1.08	1.34	1.27	1.15	1.62	1.32	1.56
50	2	**1.21**	**1.70**	**1.67**	**1.55**	**1.84**	**1.36**	**1.78**

ACKNOWLEDGMENTS

This material is based upon work supported by grant number N00014-17- 1-2558 from ONR and 69A3551747126 from the US DoT. Standard disclaimers apply

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