Power-efficient Joint Link Selection and Multihop Routing for Throughput Maximization in UAV Assisted FANETs

Payal Mittal, Santosh Shah and Anirudh Agarwal
Department of Electronics and Communication Engineering
The LNM Institute of Information Technology, Jaipur, Rajasthan, India

E-mails: {payalmittal.y19, santosh.shah, anirudh.agarwal}@lnmiit.ac.in

Abstract—This paper considers a multi-UAV network with a ground station (GS) that uses multihop relaying structure for data transmission in a power-efficient manner. In order to increase the total network performance of a flying ad-hoc network (FANET) of UAVs, the objective is to investigate the best possible multihop routing structure for data dissemination. We formulate a problem to jointly optimize the multihop routing structure with the communication link selection for a given power budget so that the overall network throughput can be maximized. It appears that the formulated problem belongs to a class of nonconvex and integer optimization problems, thus making it NP-hard. To solve this problem efficiently, it is decoupled into two subproblems i) power allocation with known Bellman Ford-based multihop routing structure and ii) link selection problem. Further, these two subproblems are independently converted into convex problems by relaxation and solved in tandem for the best suboptimal solution to the main problem. Simulation results indicate that the proposed multihop routing schemes can achieve a significant improvement in network throughput compared to the other benchmark scheme.

Index Terms—UAV, throughput maximization, multihop routing structure, power allocation, FANET, link selection, NP hard.

I. INTRODUCTION

Unmanned aerial vehicles (UAVs), commonly referred to as drones, have gained popularity in recent years owing to their enormous potential applications in wireless communication due to their high mobility, flexibility, and adaptability. The UAV is a rapidly growing market that has already found many applications in military, civilian and public domains [1]. Recently, the network of multiple UAVs grouped in an ad-hoc manner has attracted significant attention for multihop communication to extend the coverage during an emergency situation. However, UAVs are commonly deployed for aerial communication, and monitoring in some crisis circumstances, such as earthquakes and floods [2], [3]. The network in which several UAVs can share data and collaborate in an ad-hoc fashion is a FANET (flying ad-hoc network) in which each UAV can also operate as a relay [4]. Generally, FANETs comprise of a ground station (GS) and UAVs hovering and flying at a particular permissible altitude. A possible FANET scenario where all UAVs communicate bidirectional to share their information and also act as relays during information transfer to the GS via multihop. Due to the dynamic nature and high mobility of UAV ad-hoc networks, a routing protocol is required to tackle the collision and interference issues. Cooperative relaying using UAVs with an efficient multihop routing structure provides more coverage, reliable data transmission, enhanced data rates, and better network connectivity. However, few challenges remain in FANETs such as throughput maximization and power-efficient multihop routing with optimal link selection that need to be simultaneously addressed.

II. RELATED WORK

Various routing techniques have been introduced in recent years for effective data collection and dissemination. The concept of UAV-assisted cooperative communication with a multihop routing structure has been well demonstrated in the existing literature [5]–[8]. In [5], authors proposed a predictive optimized link-state routing protocol that takes the advantages of global positioning system data to predict the wireless channel quality to find the routing with minimum interruptions and delays. To address the limited energy supply and storage capability of UAV, the authors in [7] proposed a multihop routing technique based on trajectory prediction. Further in [8], the author introduced a packet arrival prediction routing protocol to increase the link durability. Moreover, an iterative distributed algorithm is proposed in [9] for multihop routing, which provides a trade-off between estimation accuracy and energy efficiency.

Furthermore, several important works investigate the problem of throughput maximization and power allocation. Specifically, [10] proposed a variable rate relaying approach to maximize the achievable rate of the system for fixed-wing UAVs. Further, the authors in [11] proposed a novel framework to optimize the system throughput by jointly optimizing trajectory and the power allocation of a single UAV-based mobile relaying network. Similarly, [12] jointly optimized the bandwidth, transmission power, UAV’s position, and transmission rate for maximizing the throughput of the system. Moreover, the authors in [13] optimized the UAV’s altitude by considering the problem of minimizing the network outage.
probability. In order to increase the average total rate of all users, the authors in [14] recently focused on trajectory optimization for a UAV-assisted communication.

Most of the above works [5], [7], [8] deal with different routing protocols to optimize the resource allocation in different ways, but the discussion on multihop routing structure with efficient power allocation to maximize the network throughput has not been covered yet in the current literature. Further, the authors in [10], [11] consider a single fixed-wing UAV for optimizing the system throughput. However, a single fixed-wing UAV in the event of a disaster (such as a flood, earthquake, or other natural disasters) may not be a productive choice where continuous monitoring is needed. In this case, rotary-wing UAVs provide a number of benefits over a fixed-wing UAVs, including as enhanced maneuverability, more affordable design, and payload capacity. Furthermore, the authors in [12], [13] considered only one rotary-wing UAV to serve the single and multiple communication pairs on the ground, respectively, while neglecting the multihop communication among the UAVs. Similarly, [15] considered the multihop single link and multiple dual-hop links to determine the performance of the system without taking into account the multihop multi-link between the transmitter and receiver.

From the above discussion, it can be observed that it is critical to design efficient routing structure with proper network flow for an efficient corporation and information exchange among multiple UAVs over multiple hops in a FANET. System performance can be further improved by appropriate power allocation. Therefore, a multihop routing with reliable and efficient power allocation to maximize the overall network throughput needs further studies. So in this work, we aim to maximize the network throughput of a FANET by jointly optimizing the UAV’s power allocation along with the multihop routing structure.

To the best of our knowledge, this is unexplored work that considers throughput maximization while optimizing a multihop routing structure for a given total power budget in multi UAV-assisted FANETs. Disaster management, rescue agencies, public safety bodies, and defense organizations may get benefited from the proposed framework for practical applications. Furthermore, public safety bodies, and defense organizations may get benefited from the proposed framework for practical applications. Further, the authors in [10], [11] consider a single fixed-wing UAV for optimizing the system throughput. However, a single fixed-wing UAV in the event of a disaster (such as a flood, earthquake, or other natural disasters) may not be a productive choice where continuous monitoring is needed. In this case, rotary-wing UAVs provide a number of benefits over a fixed-wing UAVs, including as enhanced maneuverability, more affordable design, and payload capacity. Furthermore, the authors in [12], [13] considered only one rotary-wing UAV to serve the single and multiple communication pairs on the ground, respectively, while neglecting the multihop communication among the UAVs. Similarly, [15] considered the multihop single link and multiple dual-hop links to determine the performance of the system without taking into account the multihop multi-link between the transmitter and receiver.

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The key contributions of this work are summarized as follows:

- The unique network model is proposed in Section III, in which we formulate an optimization problem to maximize network’s overall throughput while considering power allocation and communication link selection as two different variables.
- We have shown that this problem is nonconvex integer optimization problem, thus making it NP-hard.
- In order to solve this nonconvex integer optimization problem, it is decoupled into two subproblems. The first subproblem optimizes power allocation while using Bellman Ford based routing algorithm and second subproblem optimizes the multihop routing structure while using the solution of the first subproblem, which are described in Section IV.
- These two subproblems are solved in tandem to find the best global sub-optimal closed-form solution to the original problem. Then, this closed-form solution is used to construct the best routing among UAVs and from UAVs to the GS to obtain the best possible overall throughput.
- In Section V, we provide the simulation results, followed by the conclusion in Section VI.

III. NETWORK MODEL AND PROBLEM FORMULATION

A. Network Model

We consider a UAV-assisted FANET scenario in which numerous UAVs indulge in multi-hop communication as shown in Fig 1. This system model can be used in a high terrain environment where a disaster (such as an earthquake, flood, or other natural disasters) may occur. We assume that the FANET consists $n$ rotary-wing UAVs, $u \in [u_1, u_2, \ldots u_n]$ that are randomly deployed over the disaster-prone square area of approximately $20 \times 20$ km$^2$ for monitoring. We consider that each UAV is equipped with a camera, an image encoder, and a radio transceiver. We consider one ground station (GS) to receive all information picked up by UAVs. Long-distance communication between GS and far-away UAVs is not possible to establish a power-efficient FANET; however, UAVs that are in proximity to GS may communicate directly with GS. UAVs have the ability to hover and remain still over a certain location for a specific duration. The sensed data is communicated to GS using UAVs via multihop relaying.

We assume that sufficiently charged UAVs will be on standby to replace the low-power UAVs in real-time. Furthermore, we made the assumption that the spacing between UAVs is sufficiently large to prevent collisions and interference [16]. A Cartesian coordinate system is considered for simplicity of analysis. The coordinates of the $n$-th UAV are $(x_n, y_n, z_n)$. 

Fig. 1: Illustration of a UAV-assisted FANET with multihop routing structure considered in this work. All the monitored information reach to the ground station (GS) using the multihop routing, where intermediate UAVs act as a relay.
A UAV that captures the information becomes the source node and the information is transmitted to GS directly or via multihop, whichever is applicable. The coordinates of GS is given by \((x_{n+1}, y_{n+1}, 0)\). Once a UAV has arrived at its fixed position, its altitude kept constant. We assume that every UAV flies at a fixed permissible altitude to provide a line-of-sight connections.

\(L_{ij}\) is the communication link that exists between \(i^{th}\) and \(j^{th}\) UAVs. We assume all UAVs are at the same height, then the distance \(d_{ij}\) is given as,
\[
d_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2},
\]
where \(i = 1, 2, ..., n \in \mathbb{N}_0\) and \(j = 1, 2, ..., n + 1 \in \mathbb{N}\). The coordinate of GS is indicated by \(n + 1\) and \(j\) is an expected parent of \(i\). Furthermore, \(h_{ij}\) denotes the channel gain of the link, which is defined as,
\[
h_{ij} = \frac{\alpha_0}{(d_{ij})^\beta},
\]
where \(\alpha_0\) is the received power at a reference distance \(d_0 = 1\) m, \(\beta\) is the free-space path loss exponent.

We use \(P_j\) to denote the transmission power for the link \(L_{ij}\), channel bandwidth is \(B\) and the noise spectral density is \(\sigma^2\), then capacity of the link \(L_{ij}\) can be described as,
\[
C_{ij} = B \log_2 \left(1 + \frac{P_j h_{ij}}{\sigma^2 B}\right).
\]
Further, the transmission rate of the link \(L_{ij}\) is \(R_{ij}\), then
\[
R_{ij} \leq B \log_2 \left(1 + \frac{P_j h_{ij}}{\sigma^2 B}\right), \quad \forall i \in \mathbb{N}_0, \forall j \in \mathbb{N}.
\]

B. Optimization Problem Formulation

In this work, we aim to maximize the overall network throughput \(\sum_{i=1}^{n} R_{ij}\) by optimizing both variables \(P_j\) and \(L_{ij}\). The data collected by UAVs should be routed to the GS via power-efficient multihop routing paths. The optimization problem \((\mathbb{P}1)\) can be formulated as follows,

\[\text{(P1)}: \text{maximize} \sum_{i=1}^{n} \sum_{j=1}^{n+1} L_{ij} R_{ij} \]

subject to
\[
C1: \sum_{i=1}^{n} \sum_{j=1}^{n+1} L_{ij} P_j = P_b,
\]
\[
C2: P_j \geq 0, \quad \forall i \in \mathbb{N}_0, \quad \forall j \in \mathbb{N},
\]
\[
C3: L_{ij} \in \{0, 1\}, \quad \forall i \in \mathbb{N}_0, \quad \forall j \in \mathbb{N},
\]
\[
C4: L_{ij} \leq L_{jk}, \quad \forall i \in \mathbb{N}_0, \quad \forall j, k \in \mathbb{N},
\]
\[
C5: L_{ij} + L_{ji} \leq 1, \quad \forall i \neq j,
\]
\[
C6: A_{ij} = 1, A_{ij} \in \mathbb{A}, \forall i \in \mathbb{N}_0, \forall j \in \mathbb{N},
\]

The sum of associated total power for each UAV should be limited in order to maintain some communication power budget \(P_b\), and the power associated with each UAV cannot be negative according to the constraints \(C1\) and \(C2\), respectively. The constraint \(C3\) represents that \(L_{ij}\) is an integer variable indicating the status of selecting a particular link between \(i^{th}\) and \(j^{th}\) UAV, i.e., \(L_{ij} = 1\) denotes that the link is selected for communication and \(L_{ij} = 0\) denotes that the link is inactive. The constraint \(C4\) ensures that the direction of data flow is towards GS, where parent \(j\) of \(i\) and parent \(k\) of \(j\) are chosen such that the resulting information is rooted at GS. Finally, \(C5\) prevents the loops in a multihop routing path and allows the routing to head in the correct direction. \(A\) denotes the incidence matrix with elements \(A_{ij}\), represented by constraint \(C6\). The elements of incidence matrix \(A\) are given as
\[
A_{ij} = \begin{cases} 1 & \text{if } d_{ij} \leq d_{th} \\ 0 & \text{otherwise} \end{cases}
\]
where \(d_{th}\) is a maximum allowed threshold distance for any two UAVs to communicate to avoid bad channel communications. Since the problem \((\mathbb{P}1)\) is a nonconvex integer optimization problem [17], its original formulation is challenging to solve. To solve this problem, one variable is considered at a time resulting in two subproblems, which are then solved efficiently in tandem to get the near-optimal solution of the original problem \((\mathbb{P}1)\).

IV. PROPOSED OPTIMAL SOLUTION METHODOLOGY

In the following, we consider two subproblems of \((\mathbb{P}1)\), namely power allocation subproblem and link selection subproblem to optimize multihop routing.

A. Power Allocation Subproblem

In this section, we consider the first subproblem of \((\mathbb{P}1)\) to optimize power allocation for each UAV by assuming that a multihop routing structure based on Bellman Ford shortest path tree (SPT) algorithm is provided. As a result, this subproblem is only with the optimization variable \(P_j\), whereas \(L_{ij}\) is known by using SPT, in the sense that a parent of \(i\), i.e., \(j\) is known. Hence, index \(j\) from \((\mathbb{P}1)\) is omitted for brevity. So, the power allocation subproblem can be reformulated as,

\[\text{(P1.1)}: \text{maximize} \sum_{i=1}^{n} R_i \]

subject to
\[
C1': \sum_{i=1}^{n} P_i = P_b,
\]
\[
C2': P_i \geq 0, \quad \forall i \in \mathbb{N}_0.
\]

Thus, there exists an optimal solution to \((\mathbb{P}1.1)\) such that both the constraint \(C1\) and \(C2\) satisfied. Note that \((\mathbb{P}1.1)\) is a convex optimization problem, which can be solved numerically using standard convex optimization techniques such as Lagrangian method and generates the optimal solution as \(\{P_i^*\}\).

Proof: Refer to Appendix for convexity.

The Lagrangian \(\mathcal{L}\) of \((\mathbb{P}1.1)\) is described as,
\[
\mathcal{L}(P_i, \lambda, \mu_i) = R - \lambda \left(\sum_{i=1}^{n} P_i - P_b\right) + \sum_{i=1}^{n} \mu_i P_i,
\]
where \(R \triangleq \sum_{i=1}^{n} R_i\), \(\lambda\) and \(\mu_i \forall i \in \mathbb{N}_0\) are Lagrange multipliers with respect to \(C1\) and \(C2\) respectively. As \((\mathbb{P}1.1)\) is convex, the global optimal solution is provided by the
Karush-Kuhn-Tucker (KKT) point \((P^*_i, \lambda^*, \mu^*_i)\). The KKT conditions are as follows:

\[
\begin{align*}
\frac{\partial L}{\partial P_i} &= \frac{B h_i}{\sigma^2 B + P_i h_i} - \lambda + \mu_i = 0, \quad \forall i \in \mathbb{N}_0, \quad (7a) \\
\frac{\partial L}{\partial \lambda} &= \left(\sum_{i=1}^{n} P_i - P_k\right) = 0, \quad \forall i \in \mathbb{N}_0, \quad (7b) \\
\frac{\partial L}{\partial \mu_i} &= \left(\sum_{i=1}^{n} P_i\right) = 0, \quad \forall i \in \mathbb{N}_0. \quad (7c)
\end{align*}
\]

Since \(P_i > 0 \quad \forall i \in \mathbb{N}_0\), we take \(\mu_i = 0\) without loss of generality. After solving (7a), we obtain,

\[
P^*_i = \frac{B}{\lambda} - \frac{\sigma^2 B}{h_i}. \quad (8)
\]

As \(P_i > 0\), \(\frac{B}{\lambda} - \frac{\sigma^2 B}{h_i}\) should be positive \(\forall i \in \mathbb{N}_0\). Because the difference of two quantities can only provide power if each individual quantity is proper, the terms \(\frac{B}{\lambda}\) and \(\frac{\sigma^2 B}{h_i}\) can be considered as powers. So in nutshell,

\[
P^*_i = \begin{cases} \frac{B}{\lambda} - \frac{\sigma^2 B}{h_i}, & \lambda < \frac{h_i}{\sigma^2} \\ 0, & \lambda \geq \frac{h_i}{\sigma^2} \end{cases} \quad (9)
\]

\(\mu^*_i = 0\) Finally, by solving (7b) and (9), we obtain,

\[
\lambda^* = \frac{P_i^*}{\hat{P}} + \sum_{i=1}^{n} \frac{\sigma^2}{\hat{r}}. \quad (10)
\]

The following are the complexity of each stage: Bellman Ford based SPT algorithm takes \(O(nM)\) operations, where \(n\) and \(M\) are the number of vertices and edges, respectively. Generally, we have \(n < M\). Computational complexity to calculate the optimization variables \(R^*_i\), \(P^*_i\), and \(\lambda^*\) from (4), (9), and (10) takes \(O(n^2)\) operations. Thus, the overall computational cost has the order \(O(nM)\).

### B. Link Selection Subproblem

In this section, we consider second subproblem of (P1) to optimize link selection \(L_{ijk}\), that is this subproblem further optimizes the SPT based routing structure to enhance the overall network throughput given the solution of (P1.1). The optimal objective value \(\{P^*_i\}\) of the optimization problem (P1.1) will be used as the solution base for this problem. Then, the link selection subproblem can be written as (P1.2),

\[
\text{subject to } C1: \sum_{i=1}^{n} \sum_{k \in N_i, k \neq j} L_{ik} P_{ik} = P^*_i, \quad C2 : L_{ik} \in \{0,1\}, \quad \forall i \in \mathbb{N}_0, \quad \forall k \in \mathbb{N}_i, \quad C3 : L_{ik} \leq L_{ki}, \quad \forall i \in \mathbb{N}_0, \quad \forall k \in \mathbb{N}_i, \quad C4 : L_{ik} + L_{ki} \leq 1, \quad \forall i \neq k,
\]

where index \(k\) indicates all possible one-hop neighbours \(N_i\) of UAV \(i\) that can be chosen as the next best parent of \(i\), if for the same \(P^*_i\), \(R_{ik} > R_{ij}\) (\(j\) is the previous parent of \(i\)).

(P1.2) is a non-convex optimization problem due to the non-convex constraint C2, making it an NP-hard integer optimization problem. Therefore, the optimal solution is not feasible. This problem is solved by executing an approximate relaxation over the variable and then solving the relaxed problem. We can cast this problem into an equivalent problem formulation by relaxing C2 constraint so that it can take values anywhere in the range \(0 \leq L_{ik}^* \leq 1\).

Let \(D_{ik} \in \mathbb{D}\) be the elements of network’s directional matrix, so that

\[
D_{ik} = \begin{cases} 1 & \text{if } k \text{ is the parent of } i \\
-1 & \text{if } i \text{ is the parent of } k \\
0 & \text{otherwise} \end{cases} \quad (11)
\]

where \(a\) is positive rational integer. With this notation, we can reformulate problem (P1.2) as follows:

\[
(\text{P1.3}): \text{maximize } \sum_{i=1}^{n} \sum_{k \in N_i, k \neq j} L_{ik}^* R_{ik} D_{ik}
\]

subject to \(C1: \sum_{i=1}^{n} \sum_{k \in N_i, k \neq j} L_{ik}^* P_{ik} = P^*_i, \quad C2 : 0 \leq L_{ik}^* \leq 1 \quad \forall i \in \mathbb{N}_0, \quad \forall k \in \mathbb{N}_i,
\]

where \(L_{ik}^* \in [0,1]\) is the relaxed version of variable \(L_{ik}\). In this case, the objective function is convex function over \(L_{ik}^*\) and all other constraints are linear over \(L_{ik}^*\), resulting in a well-defined convex problem. Now, we describe a simple method to solve the relaxed problem (P1.3) very efficiently but approximately using log barrier method \([17]\), that is, the interior point method is used to solve this problem. Then, the problem (P1.3) can also be posed as:

\[
(\text{P1.4}): \text{maximize } \phi(L^*)
\]

subject to \(C1: \sum_{i=1}^{n} \sum_{k \in N_i, k \neq j} L_{ik}^* P_{ik} = P^*_i, \quad \text{where } \phi(L^*) = \sum_{i=1}^{n} \sum_{k \in N_i, k \neq j} L_{ik}^* R_{ik} D_{ik} + \frac{1}{2} \sum_{i=1}^{n} \log(L_{ik}^*) + \log(1 - L_{ik}^*) \text{ and } \gamma > 0 \text{ to set the quality of approximations. The optimization problem (P1.4) is with concave objective and equality constraint is linear, therefore it can be efficiently solved by the Newton’s method \([17]\). In this method, at each step Newton search step \(\Delta L^*\) is computed, which is expressed by}

\[
\Delta L^* = (\nabla^2 \phi)^{-1} \nabla \phi - \left(\begin{array}{c} P^*_i \nabla^2 \phi \end{array}\right)^{-1} \nabla \phi \left(\begin{array}{c} P^*_i \nabla^2 \phi \end{array}\right)^{-1} P_i \quad (12)
\]

where \(\nabla \phi\) and \(\nabla^2 \phi\) are the gradient and Hessian of function \(\phi\), respectively. We take \(\text{diag}(L^*) P_i = P^*_i 1\) as initial point, where \(P_i^T = [P_{i1}, P_{i2}, \ldots, P_{ik}]\) is a column vector with elements as all possible parent’s link power.

The backtracking line search is then used to take the equality constraint into account and update \(L^*\) by replacing it with \(L^* + \tau \Delta L^*\), where \(\tau\) \(\in (0,1]\) is step size for
backtracking line search. We stop when the Newton decrement 
\(- \nabla \phi (L^*)^T \Delta L^* \leq \varepsilon\), for \(\varepsilon > 0\) sufficiently small. In our problem, for completeness we provide expressions for the first and second derivatives of \(\phi\) in terms of its gradient \(\nabla \phi\) and the Hessian \(\nabla^2 \phi\), which can be written as:

\[
(\nabla \phi)_i = \sum_{k \in N_i, k \neq j} R_{ik} D_{ik} + \frac{1}{\gamma} \left( \frac{1}{L_{ik}^*} - \frac{1}{1 - L_{ik}^*} \right).
\]  

(13)

The Hessian \(\nabla^2 \phi\) can be written as:

\[
(\nabla^2 \phi)_i = -\frac{1}{\gamma} \left( \frac{1}{(L_{ik}^*)^2} + \frac{1}{(1 - L_{ik}^*)^2} \right).
\]  

(14)

The solution of \((P1.4)\) that is \(\{L_{ik}^*\}\) generated from the above procedure and the solution \(\{P_i^*\}\) of \((P1.1)\) are then used to update the overall network throughput.

Now, we provide an analysis of the complexity to compute the Newton step \(\Delta L^*\) using (12) at each iteration. First we calculate \(\sum_{k \in N_i, k \neq j} R_{ik} D_{ik}\), which costs \(O(n^2)\). Then, we need to compute the Hessian \(\nabla^2 \phi\) using (14), which cost \(O(n^3)\). Thus, the overall computational cost has order \(O(n^3)\).

V. RESULTS AND PERFORMANCE EVALUATION

This section deals with the validation and other numerical results along with the key optimal insights. Unless explicitly stated, we have considered, \(B = 10\) MHz as the total system bandwidth, \(\alpha_0\) is set to be \(\left(\frac{\pi f}{c}\right)^2\), where \(c\) is the speed of light and the centre frequency \(f = 1\) GHz. The noise power spectral density corresponds to \(\sigma^2 = -174\) dBm/Hz. The UAVs are placed such that the minimum altitude \(H\) is 150 m. All the results are generated by averaging over 100 iterations with different random seeds.

Network throughput \(R\) is plotted against \(P_b\) in Fig. 2 to determine the best choice of number of UAVs \((n)\) used in the considered square area of \(20 \times 20\) km². In addition, the impact of different numbers of \(n\) on \(R\) has been analyzed. In order to minimize recurrence in the sensed data, curves are generated based on randomly chosen UAV coordinates with the smallest distance between them. Our approach assigns transmission power \(P_i\) across all UAVs in the optimal way. Initially \(R\) increases significantly, because \(R \propto P_i\) \(\forall i \in N_0\).

However, beyond \(n = 25\), there is no significant change in \(R\). As a result, \(n = 25\) appears to be sufficient to monitor the desired area. Although \(R\) is more for higher values of \(n\) but the cost of deploying such a large number of UAVs is also higher.

![Fig. 3: Random UAV deployment for the desired square area with the best choice of number of UAVs discussed.](image)

![Fig. 4: Effect of \(P_b\) on \(R\) for different routing schemes compared with the benchmark scheme [15].](image)

In Fig. 4, the throughput \(R\) achieved by both the subproblems are plotted with respect to \(P_b\). It can be observed that the problem \((P1.4)\) significantly outperforms \((P1.1)\) because...
solution of power allocation subproblem is used in link selection subproblem, which further improves the throughput by interchanging the appropriate child-parent links. In this figure, we have also compared our work with the benchmark scheme investigated in [15]. It can be observed that the proposed strategies perform better in terms of increased network throughput than the benchmark system.

VI. CONCLUSION

In this paper, we investigated the problem of maximizing the overall network throughput for UAV-assisted FANET via jointly optimizing multihop routing structure as well as power allocation. It is achieved by first computing the number of UAVs that can be deployed in a considered scenario. From the results, it can be found that \( n = 25 \) is the best choice for a given square area of \( 20 \times 20 \text{ km}^2 \). The main formulated problem appears to be non-convex when optimizing both the variable jointly. In order to solve the problem efficiently it is decoupled into two subproblems. A global sub-optimal solution for allocating the power to each UAV is found from the power allocation subproblem. Then, the link selection subproblem is solved to further improve the network throughput using the solution of the first subproblem. Additionally, we have presented the simulation results to demonstrate the effectiveness of the proposed routing structure. Furthermore, we have also compared our work with a benchmark scheme, where the proposed schemes show a considerable performance improvement in maximizing the overall network throughput for UAV-assisted communication service in disaster areas, a comprehensive survey,” IEEE Commun. Surv. & Tut., vol. 22, no. 2, pp. 1071–1120, 2020.

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