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THROUGHPUT MAXIMIZATION IN UAV-ASSISTED WIRELESS NETWORKS

Rizwana Shahzadi[1], Mudassar Ali[2], Asim Shahzad[*3], Muhammad Irfan Aslam[*4]

[1,2]*University of Engineering and Technology, Taxila 47050, Pakistan*
[2]*National University of Sciences and Technology, Islamabad 44000, Pakistan*
[*3]*Federal Urdu University, Islamabad, Pakistan*
[4]*University of education Lahore*

[*3]drasim.shahzad@fuuast.edu.pk

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Corresponding Author: *
Asim Shahzad

Abstract
Today we are living in an era where technology and communication means are updating at a breakneck pace. Just a few decades back we were using applications that required only a kbps data rate. But with massive breakthrough development in interactive multimedia-based applications side, high data rate requirements became crucial. The evolution of 5G technology has acted as major breakthrough toward the high data rate and connectivity demand of the users using interactive multimedia-based applications. UAV-based 5G networks have become a hot research area due to several basic advantages associated with UAVs e.g., fast deployment, LoS communication path, maneuverability, and many more. This work has considered a 5G communication scenario in which the UAV is also acting as a base station along with Macro and small cells. OAA-based algorithm is presented to achieve optimized resource allocation.

I. INTRODUCTION

IN past, communication was an only exchange of text or voice messages. Later, with the advancement of communication standards and protocols, images and picture transfer became a part of communication. Recently with the development of interactive multimedia applications e.g., video streaming, and live gaming both audio and video have become a crucial part of communication. With the advancement of technology, communication standards have also evolved from 1G to 5G in order to satisfy the high data rate and connectivity demand of end-users involved in such multimedia types of applications. The shift from 4G to 5G is not just one step it is actually a major breakthrough in wireless communication. It offers several advantages as compared to the existing 4G LTE network [1]. Some are as follows:

- data rate up to 10 Gbps (10 to 100x improvement)
- Low latency rate(less than 5ms)
- 100 times more connected devices
- 99.999% network availability
- 90% power reduction
- Better Security

Several technologies have evolved to provide 5G communication services e.g., cell densification, massive MIMO, edge computing, mm-wave, beamforming, NOMA(nonorthogonal multiple access), etc. However, each of them has several limitations for example interference is related to cell densification, LoS, and hardware size are related to mm-wave. Therefore researchers are working to develop new technologies for 5G communication. Recently UAV assisted 5G communication has emerged as a promising new trend in 5G communication.

For efficient wireless communication heterogeneity was introduced. In heterogeneous networks, different wireless networks (WLAN, cellular, etc) work together to provide a seamless service to end users with optimized resource allocation between a variety of wireless networks. Recently UAV assisted HetNet has appeared in limelight. In UAV-assisted HetNet, UAVs serve as flying wireless base stations [2].

Recently UAV assisted HetNet has become an important research direction because of several advantages associated with UAVs.If there is some situation in which a large crowd has suddenly appeared in a certain specific area e.g., a festival or match for a short duration of time. UAVs best suitable candidate in such situations. A flying UAV BS can be deployed in such a situation to handle connectivity and the high data rate demand of end-users without re-planning the whole existing wireless scenario. And once the crowd goes away, deputed UAV BS can easily move to any other location. UAVs are pilot-free vehicles, therefore; they are very suitable candidates for communication or rescue services in any disaster situation. In case of any natural (flood, earthquake, etc.) or man man-made disaster (atomic explosion, etc.) already existing wireless infrastructure vanishes along with the disaster. In order to run search and rescue operations, there is an urgent need for wireless communication infrastructure to be deployed to save the lives of people. Any conventional wireless infrastructure deployment can't be made at that faster pace as the UAV base station.UAVs are pilot-less, so they can actually be deployed much closer to the end-users at disaster scenes to actually help people caught in trouble [3].

Despite several benefits of UAVs, some associated challenges that need to be addressed are 3D placement, Resource allocation, trajectory planning, on-board energy limitation, backhaul connectivity, and several others. Among these challenges resource management between UAV BS and other wireless networks is the most crucial one in a heterogeneous network environment. In HetNet resources e.g., channel, bandwidth, energy, and power are shared between UAV BS and other wireless networks. Optimized resource allocation is necessary to get the most out of the wireless communication network.

The rest of the paper is organized in such a way that section 2 contains related literature reviews and contributions to the work. The system model and problem formulation are presented in section 3. Section 4 Contains results and future research directions.

TABLE I: **Resource allocation in UAVs based communication networks, Concave-Convex Procedure(CCCP) , Maximized HMTDs(human portable/wearable MTDs), UNR(UAB network Access and resource Allocation), Deep Reinforcement Learning(DRL), Successive Convex Optimization (SCO)**

Reference	**Objective**	**Problem Type**	**Algorithm**	**Constraint**
4	Utility Maximization	Non Convex	Bisection Search, (CCCP)	Power, Data Rate
5	Maximized HMTDs	Convex	UNR	Transmission Power
6	Maximized Throughput	Convex	Dynamic resource allocation	Data rate
7	Maximized energy efficiency	Optimization	DRL	Power
8	Maximize throughput	Non Covex	FDMA/TDMA, SCO	Power
9	Maximized Capacity	Opitmization	Stochastic geometry	Coverage

II. LITERATURE REVIEW

Resource allocation in UAV-assisted HetNet is a complicated task because resources are jointly shared between existing terrestrial infrastructure and UAV BS. This joint resource allocation is a multidimensional task that makes it a complex process. Author in [4] has proposed a Software-Defined Cellular network (SDCN) based placement and resource allocation scheme which maximizes the network utility while maintaining a trade-off between associated users and allocated power values. It also ensures that the minimum QoS criteria of covered users are also satisfied. Later on, the non-convex problem is decomposed into two sub-problems, Optimal altitude to radius ratio and optimized resource allocation problem. Bisection search and Convex Concave procedures are utilized to get the optimized solution. Resource allocation in UAV-assisted M2M (machine to machine) communication is a disaster is presented in [5]. UAV BS on-board battery is a very scarce resource and directly controls its hovering time. So in order to maximize the rescue efficiency and hovering time author has considered to minimize the transmitted power. UAVs in wireless communication are a fast-growing research direction.

Due to a large number of UAVs coming into the communication field, the spectrum for them is getting shrunk. Only the efficient utilization of spectrum resources can maximize the network efficiency. Work in [6] has focused on the dynamic approach of spectrum allocation problem to flying UAV BS to maximize the network throughput while also maintaining the minimum data rate requirement as well. The author in [7] has considered a UAV-based IoT framework where UAVs are involved to collect data from remotely located IoT nodes. Since IoT nodes and UAVs both are battery-operated therefore efficient energy utilization is the only way to maximize network efficiency. It has presented Deep Reinforcement Learning (DRL) based decision-making in order to efficiently allocate power and time slot in UAV-based IoT systems. Efficient resource allocation and base station placement in a Wirelessly powered downlink UAV-assisted cellular network is considered in [8]. Resource allocation and BS placement are optimized in an alternate fashion. Two resource allocation schemes Frequency division multiple access(FDMA) and Time-division multiple access (TDMA) are considered to maximize the common throughput. For placement optimization successive convex optimization is considered to maximize the lower bound. UAV-based wireless networks are considered very suitable candidates to provide communication services in a disaster area. The author in [9] has considered UAV-supported wireless mesh networks. In order to maximize the UAV network efficiency, not only air-to-air but air-to-ground communication is also required. UAVs are considered in a three-dimensional poison point distribution format. Stochastic geometry is utilized to investigate the impact of UAV transmit power, density, and vertical range.

Recent studies have increasingly focused on advanced optimization techniques to enhance throughput in UAV-assisted wireless networks. Joint optimization of UAV trajectory, user association, and resource allocation has been widely recognized as an effective approach to improving system performance and ensuring fairness among users [10], [11]. In particular, mobility-aware 3D trajectory optimization combined with adaptive resource allocation has demonstrated significant improvements in minimum user throughput in dynamic wireless environments [10]. Moreover, multi-UAV systems and swarm-based architectures have been explored to further enhance network capacity, coverage, and scalability, especially in IoT and large-scale data collection scenarios [12], [16].

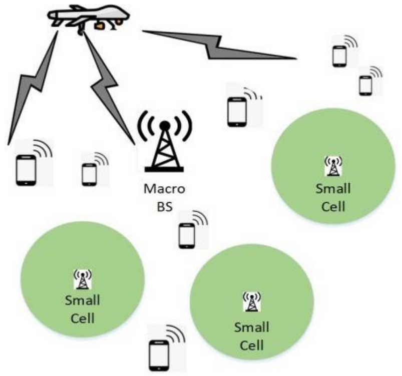

Fig. 1: UAV assisted HetNet Communication Scenario

In recent years, machine learning-based approaches, especially deep reinforcement learning (DRL), have gained attention for solving complex and dynamic optimization problems in UAV-assisted networks, enabling adaptive and real-time throughput maximization [13], [17]. Furthermore, the integration of emerging technologies such as reconfigurable intelligent surfaces (RIS) with UAV platforms has opened new directions for improving spectral efficiency and signal propagation, thereby significantly enhancing system throughput [14], [18]. Additionally, recent works have investigated UAV-assisted wireless systems in the context of beyond-5G and 6G networks, highlighting their potential to provide flexible, scalable, and high-capacity communication solutions due to improved line- of-sight connectivity and dynamic deployment capabilities [11], [15], [19]. These studies collectively indicate a shift toward intelligent, adaptive, and hybrid optimization frameworks for throughput maximization in next-generation UAV-assisted wireless networks.

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The main contributions of this research work are listed below:

- This work has presented a mathematical formulation for UAV-assisted HetNet containing UAV, Macro, and small cell BSs.
- An OAA-based heuristic is proposed for efficient resource allocation between UAV Bs and conventional HetNet.
- Network throughput and user assignment are investigated in UAV assisted HetNet for different data rate requirements.
- Substantial simulation work has been performed to ensure the credibility of the proposed scheme.

III. SYSTEM MODEL AND MATHEMATICAL MODELLING

UAV-assisted HetNet scenario is shown in Fig 1. It contains Macro BS, small cells, a flying UAV BS, and end-users. Let the Macro BS cover a radius R. UAV is positioned at an altitude H from the ground in such a way to cover as many users as possible. Users have three possibilities for BS services Macro BS, small cell BS, or UAV BS but one user can take communication service from one BS at a time. Let B denote the base stations $b \in B$ and $B = \{Macro, small, UAV\}$.Let U is denoting end-users and $u \in U$ and $U = \{1, 2, 3, 4.....\}$. Let's consider a binary indicator j^u. This binary indicator is representing which user is connected to which BS. $j_b^u \in \{0, 1\} \forall b \in B, u \in U$ and $U \nRightarrow \{1, 2, 3..\}$. $j_b^u = 1$ represents that u^{th} user is connected to b^{th} base station.

$$j_b^u = \begin{cases} 1 : u^{th} \text{ user is connected to } b^{th} \text{ base station} \\ 0 : \text{otherwise.} \end{cases} \quad (1)$$

Downlink power is represented by p^u_b.It shows the power allocated to u^{th} user by b^{th} base station at the time of connectivity. Allocated channel between u^{th} user and b^{th} base station is represented by h^u_b. The channel capacity allocated to u^{th} user at

base station b can be represented in mathematical form as

$$C^u_b = log_2(1 + (p^u_b h^u_b)/N_o) \tag{2}$$

where

- p_b^u is allocated power in downlink to u^{th} user and b^{th} base station.

- h_b^u is channel gain in downlink between u^{th} user and b^{th} base station.

$$.h_b^u = \underline{h}_b^u \zeta G_1 (d1/d) \quad (3)$$

  - h_b^u is Rayleigh random variable.
  - G_1 is antenna gain
  - d_1 is antenna far field distance
  - d is distance between Tx and Rx
- N_o channel noise vale

TABLE II: Notations/Acronym Used for UAV HetNet

Symbol	Definition
UAV	Unmanned Aerial Vehicle.
j_b^u	binary indicator indicating that u^{th} user is communicating with b^{th} base station.
B	Set of Base Stations.
U	Set of end users.
N_O	Channel noise value.
C_b^u	Allocated capacity to u^{th} user at b^{th} BS .
p_b^u	Allocated power to u^{th} user at b^{th} BS .
h_b^u	Rayleigh Random Variable
G_1	Antenna gain value.
d_1	Antenna far field distance.
d	distance between Tx and Rx .

Lets consider Cartesian coordinate system in which base stations coordinates are $\{x_b, y_b, z_b\}$ and ground located user coordinates are $\{x_u, y_u, 0\}$. user, Macro, and small cell BS are located on the ground so the z component is 0 for them however UAV is flying in the air so the z component is $Z_b = H$ for UAV BS. Optimized UAV placement means placing a circular disk with coverage region C_{uav} and radius R_{uav} on a horizontal plane in such a manner it provides coverage to as many end users as possible. (x_d, y_d) are UAV circular disk coordinate values. Z_u is a binary indicator.

$$Z_u = \begin{cases} 1 : \text{User u is in UAV coverage region} \\ 0 : \text{otherwise.} \end{cases}$$

(4)

$$Z_u((x_u - x_d)^2 + (y_u - y_d)^2) \le R_{uav}{}^2 \quad (5)$$

if Z_u is zero equ 5 can be updated to equ 6 as follows:

$$(x_u - x_d)^2 + (y_u - y_d)^2 \le R_{uav}{}^2 + M(1 - Z_u) \quad (6)$$

Addition of large constant value M will ensure that equ 5 is satisfied for any value of (x_d, y_d) in case Z_u is 0.

$$j^u_b \in \{0, 1\}, \forall b \in B \forall u \in U \quad (7)$$

J^u_b value 1 indicate that user u is served by BS b.At a time only one BS should be accessible for each user as given in C2.

$$\sum_{b \in B} j^u_b \le 1 \quad (8)$$

$$\sum_{b \in B} \sum_{u \in U} p^u_b \le P_b \quad (9)$$

Power allocated to all users over BS *Macro, Small, UAV* must be less than the total power of that BS as given in C3.capacity maximization problem can be written as follows:

$$\max \sum_{b \in B} \sum_{u \in U} C^u_b j^u_b \quad (10)$$

Subject to:

C1 : $((x_u - x_d)^2 + (y_u - y_d)^2) \le Ruav^2 + M(1 - z_u)$

C2 : $\sum_{b \in B} j^u_b \le 1 \forall u \in U$

C3 : $\sum_{b \in B} \sum_{u \in U} p^u_b \le P_b$,

C4 : $D_u \le D$,

Equ 10 shows a MINLP (Mixed integer nonlinear problem) capacity maximization problem which is usually NP-hard and difficult to solve. One way is to get an optimized solution by an exhaustive search that is to go through all possible combinations to get an optimized result which is an extremely nonpractical approach due to the cost and complexity involved.

IV. PROPOSED METHOD / SOLUTION APPROACH

Problem in equ 10 is showing a MINLP. Its objective function and constraints are nonlinear and variables are of mixed integer nature. One way to solve such kinds of problems is to use an exhaustive search algorithm which is not a suitable solution because as the number of users increases, the complexity of the algorithm also increases, Such kinds of problems can be solved by the outer approximation algorithm (OAA) based Branch and Bound Method which offers low complexity level even with increased no of users. This work has considered OAA based ε optimal solution for presented MINLP. In Branch and bound method and original MINLP is divided into two sub-problems. One is the primary problem and another one is the master problem. The primary problem is nonlinear in nature whereas the master problem is the Mixed Integer Linear Problem(MILP). Firstly newly composed NL sub-problems are solved with binary or mixed integer initial values to obtain an upper bound solution. Master MILP is formulated by adding linearization to objective functions and constraints that are actually Non-linear in nature to make them linear. master problem is in fact a relaxed version of the original MINLP, therefore its solution provides a lower bound value of the actual MINLP solution. After solving both primary and master problems lower and upper-bound solutions are compared. The only comparison between them can decide whether an optimal solution has been reached or not

if yes then alright otherwise next iteration with new variable values is performed. Lets consider objective function by Z , constraints C1 to C4 by ϕ_{c1-C4}, continuous variables by $\wp = \{\wp_m, \wp_{sc}, \wp_{uav}\}$ and discrete variable set by $\psi = \psi \cup \wp$.

Algorithm 1: Outer Approximation Algorithm

```
$\vee \leftarrow 1$
Initialize $\psi$
$\varepsilon \leftarrow 10^{-3}$
$Convergence \leftarrow FALSE$
while $Convergence == FALSE$ do
    $\wp^{\vee} \leftarrow (\arg\min_{\wp} \; -Z(\psi, \wp)$
        subject to $\phi_{c1-c8}(\psi, \wp) \le 0;$
    UpperBound $\leftarrow Z(\psi^{\vee}, \wp^{*})$
    $(\psi^{*}, \wp^{*}, \varphi^{*}) \leftarrow$ arg min $\varphi$
        $\psi, \wp, \varphi$
        subject to
        $\varphi \ge -Z(\psi^{\vee}, \wp^{\vee})$
        $-\nabla K(\psi^{\vee}, \wp^{\vee})\,(\wp - \wp_0^{\upsilon})$
        $\phi_{c1}$
    Lower Bound $\leftarrow -\nabla\phi_{c1-c8}(\psi^{\vee}, \wp^{\vee})\,(\wp - \wp_0^{\upsilon}) \le 0$
    if Upper Bound $-$ Lower Bound $\le \varepsilon$ then
        $Convergence \leftarrow TRUE$
    else
        $\vee \leftarrow \vee + 1$
        $\psi^{\vee} \leftarrow \psi^{*}$
    end if
end while
```

I. SIMULATIONS AND RESULTS

In this section results for the proposed branch and bound (OAA) algorithm for UAV-assisted HetNet is presented. To implement Branch and bound algorithm open source nonlinear mixed integer programming (BONMIN) is used and all simulations are done in MATLAB. Simulations are performed to show that the proposed UAV-assisted HetNet performs much better as compared to Conventional terrestrial networks containing Macro and small cells only.

Simulations are performed to optimize the network capacity in terms of throughput and user assignment. Simulations have used $P_m = 8$, $P_s = 4$, $P_{UAV} = 8$ watts. The antenna gain value is 50. The coverage region is considered a 1000m area. The noise factor is also considered while performing simulations. investigations are performed for an increasing number of end users. Total users vary from 2- 40. Network Throughput in Mbps is optimized for UAV-assisted HetNet in presence of noise only and also in presence of interference as well and it is compared with Macro only network throughput capacity. While performing simulations users required data rate is also considered and network throughput for three different data rates is compared with Macro only situation. Fig 2 shows UAV heterogeneous network Capacity in Mbps. Network capacity is analyzed for increasing no of users from (2-40) for three different cases. In case 1 UAV assisted HetNet is considered in the noise-only scenario. In the second case, interference is also considered in

UAV-assisted HetNet. In the third and last case, the Macro only scenario is considered. Simulations show that the Proposed resource allocation method has resulted in a UAV-assisted HetNet capacity that is highest among all three cases and this trend is also consistent with an increasing number of users as well and reaches at 53Mbps at 40 users case. The user-required data rate is also considered a performance metric. UAV-assisted HetNet capacity is investigated for three different data rates {.25, 1, 3}*Mbps*. Simulations are performed for an increasing number of users. Simulations show that for data rate .25Mbps HetNet associated users are maximum and also increases with an increasing number of users.

II. CONCLUSION

UAVs are a suitable candidate for future 5G communication networks due to several advantages associated with them e.g., fast and easy deployment in disaster areas to replace existing terrestrial infrastructure that is vanished due to disaster is the biggest among them. Resources are always shared between UAV BS and terrestrial BS in the case of UAV-assisted HetNet.So efficient resource utilization is crucial to network efficiency. This work has proposed an OAA-based branch and bound approach to optimally allocate resources between UAV, macro, and small cell BSs. extensive MATLAB simulations are performed to prove the efficiency of the proposed scheme in terms of network throughput and user assignment.

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