On the Association of Small Cell Base Stations with UAVs using Unsupervised Learning

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***Abstract*—Small cell networks (SCNs) offer a cost-effective coverage solution to wireless applications demanding high data rates. However in SCNs, a challenging problem is the proper management of backhaul links to small cell base stations (SCBSs). To make a good backhaul link, perfect line-of-sight (LoS) communication between the SCBSs and the core network plays a vital role. In this study, we use the idea of employing unmanned aerial vehicles (UAVs) to provide connectivity between SCBSs and the core network. We focus on the association of SCBSs with UAVs by considering multiple communication-related factors including data rate limit and available bandwidth resources of the backhaul. In particular, we address the optimum placement of UAVs to serve a maximum number of SCBSs while considering available resources using unsupervised *k*-means algorithm. Numerical results show that the proposed approach outperforms the conventional approach in terms of associated SCBSs, bandwidth consumption, available link utilization, and sum-rate maximization.**

***Index Terms*—Drones, unmanned aerial vehicles (UAVs), small cell base stations, fronthaul/backhaul network, unsupervised learning.**

I. Introduction

The rapidly growing number of cellular users and their increasing demand for higher data rates mandates novel advancements in cellular technologies. To this end, the fifth generation (5G) and beyond 5G systems are looking into different solutions to meet the arising capacity and coverage demands. Heterogeneous networks (HetNets) have already been proposed in 3rd Generation Partnership Project (3GPP) keeping in view the spectrum crunch and coverage issues. The traditional methods to route the traffic between small cell base stations (SCBSs) and core network include wired communication (e.g., fiber optics) or wireless microwave/millimeter wave (mmWave) technology [1], [2]. Wireless communication links are further divided into line-of-sight (LoS) and non line-of-sight (NLoS) communication paths. LoS communication path is served using the free space optic (FSO) or mmWave technology but their short communication range is a major problem. Whereas, NLoS communication links have no coverage problems but suffer from high path-loss, low data rate and high transmission power demands.

Recently, the idea of using UAVs or networked flying platforms (NFPs), or drones as aerial hubs is introduced to route the traffic over backhaul links [3]. Keeping in mind the power, bandwidth and deployment cost constraints, unmanned aerial vehicles (UAVs) are an appealing technique to provide LoS communication links between transmitters and receivers [4]. Hence, traditional terrestrial backhaul network can be replaced by UAVs to provide a better communication link between the backhaul and SCBSs. The UAVs are categorized into three major types based on their altitude from the ground surface; low altitude platforms (LAPs), medium altitude platforms (MAPs) and high altitude platforms (HAPs) having a maximum height less than 5 km, between 5-10 km and greater than 10 km, respectively. However, there are many technical challenges associated with this type of communication such as the association of SCBSs with UAVs, path planning, hover time maximization, and their placement according to their available energy levels. Despite the fact that UAVs offer a promising approach to meet the higher data rate demand of cellular users in dense HetNets, the densification of SCBSs and their connectivity with the core network, known as fronthaul/backhaul network remains a key issue. In this paper, we investigate the optimum position of UAVs to route the uplink/downlink traffic of cellular users between the SCBSs and the core network. Specifically, the association problem of SCBSs with the UAV-hubs is addressed.

A. Related Work

In a very short span of time, the popularity of UAVs has grown to an irresistible level, and the communication techniques between UAVs and the ground nodes is addressed by many researchers. In [5], an air-to-ground (ATG) model for the communication between the UAVs and ground small cells is presented. Afterwards, by considering the fixed path-loss between the UAV and ground node, a mathematical expression was derived by the same authors to estimate the maximum geographical area covered by a UAV [6]. Finally, in [7], considering the height and distance between the two UAVs, the geographical area covered by them is optimized.

Considering the scope of our work, in particular, the association of UAVs with ground users and their optimum placement is studied by a few researchers [8]–[16]. First of all, association of UAV with ground nodes was addressed by

[8], by considering only one UAV with signal-to-noise-ratio (SNR) as a quality-of-service (QoS) measure. Later on, the association problem was resolved by [9], considering multiple constraints such as backhaul data rate, available bandwidth to a UAV, and maximum path-loss for the case of single UAV as an aerial base station (BS). However, both the works presented in [8] and [9], solve the association problem using exhaustive search algorithms, which are computationally complex and therefore, impractical. Afterward, the aforementioned problem was addressed in [10] by using multiple UAVs as aerial BSs depending on the requirements of ground users and their available resources. In [10], the users are associated based on the best received signal-to-interference-plus-noise-ratio (SINR), and then UAVs are placed to solve the optimization problem using the practical swarm optimization (PSO) algorithm. However, the downside of PSO is low convergence rate at high computation cost in the iterative process.

In [13], by distributing the ground users, UAVs and terrestrial BSs, optimal transport theory is adopted to associate the ground users. The objective was to obtain delay optimal cell association. Finally, in [14]–[16], the association of SCBSs with UAVs was addressed by considering the backhaul data rate, available bandwidth to a UAV, and the number of links as association constraints. In the first attempt, SCBSs are distributed using *Matern type-I* hardcore process and then UAVs are computed based on the available link constraint and then distributed using the same process. The priority was given to the SCBSs demanding maximum data rate [14], minimum data rate plus bandwidth [15], and higher spectral efficiency [16]. However, in [14]–[16], less number of SCBSs are served by UAVs. Also, the available resources are not efficiently utilized.

B. Our Contribution

In this paper, we find the optimum location of UAVs for the association problem discussed in [14]–[16]. The proposed approach considers the optimal placement of UAVs to serve the maximum number of SCBSs by keeping in view the constraints of backhaul data rate, available bandwidth, and number of requests that each UAV can accommodate. In particular, given the distribution of SCBSs in dense HetNets, the optimum position is found by using unsupervised k-means algorithm for the placement of UAV. The results show that the proposed approach results in serving maximum number of SCBSs for all types of demands (either serving maximum, minimum or spectral efficient data rates).

The remainder of this paper is organized as follows. In Section II, we present the system model, in Section III problem formulation and proposed approach is described. Section IV focuses on the results and their discussions. Finally, Section V concludes the paper and gives some future directions.

II. System Model

Consider a HetNet shown in Fig. 1 where the association problem for various network entities is shown. There are three major parts of the HetNet namely SCBSs, UAVs, and

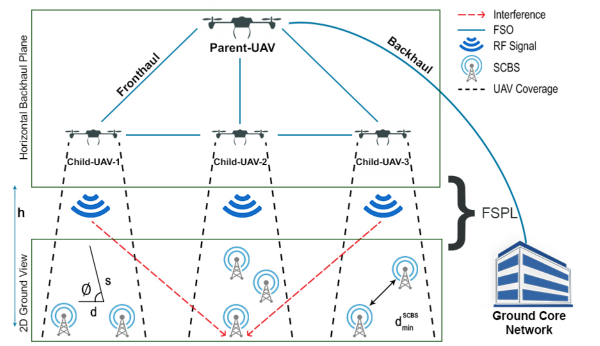

Fig. 1. Pictorial representation of Association problem.

a ground core network gateway. Let $\mathcal{N}$ and $\mathcal{M}$ be the set of all SCBSs and UAVs, respectively and let $\mathcal{M}_0$ be the singleton set representing the parent-UAV. Further, we assume that the total number of elements of sets $\mathcal{N}$ and $\mathcal{M}$ are denoted by N and M, respectively. Thus, N SCBSs are communicating with the M UAVs, where the height of a UAV from a ground SCBS is represented as h. We assume that all the M UAVs can share control information including SINR of each UAV to SCBSs, demanded data rate and required bandwidth of each SCBS, with one another. The parent-UAV is placed slightly at a higher height such that perfect LoS communication is possible from the M UAVs. In the considered model, we call the M UAVs as child-UAVs. Also, all the M UAVs directly share their information with the parent-UAV through FSO links. Moreover, parent-UAV is connected with the ground core network through another FSO link. In the above scenario, we assume that the system model does not change for the time of operation and N SCBSs are active in this period. Next, we present the path-loss model for the communication between N SCBSs and M UAVs. Then later on, we formulate the problem.

For the communication between the UAVs and SCBSs, ATG path-loss model is adopted. The ATG model is divided into two states, that is, LoS and NLoS communication links. In LoS scenario, the probability of LoS, $\mathbb{P}_{\text{LoS}}$ is an important factor and it is dependent on the height, location, angle, and obstacles between a UAV and a ground node, and is given in [5] and [6] as

$$\mathbb{P}_{\text{LoS}} = 1 + \Big[\alpha \exp\big\{-\beta(\phi-\alpha)\big\}\Big]^{-1}. \tag{1}$$

Also, $\mathbb{P}_{\text{NLoS}} = 1 - \mathbb{P}_{\text{LoS}}$. The parameter α and β in (1) are constants and solely depend on the operational environment, and ϕ is the angle (in degrees) between an SCBS and a UAV given by $\phi = \tan^{-1}\left(\frac{h_j}{d_i^j}\right)$, where d_i^j denotes the horizontal Euclidean distance between the j^{th} UAV and i^{th} SCBS and h_j is the height of the UAV. The symmetry is assumed for all UAVs, which implies that they are at the same height. The position of UAVs and the SCBSs in a Cartesian coordinate system is denoted as (x_j, y_j, h_j), and (x_i, y_i), respectively.

The total path-loss (expressed in dB) including fading attenuation F between the UAV and a SCBS is given as

$$\Lambda = K_0 + \mathbb{P}_{\text{LoS}}\mu_{\text{LoS}} + \mathbb{P}_{\text{NLoS}}\mu_{\text{NLoS}} - F, \tag{2}$$

where $K_0 = 10\log_{10}\left(\frac{4\pi s f_c}{c}\right)^{\gamma}$, which is the free-space-path-loss (FSPL), f_c is the carrier frequency, c is the speed of light, γ is the path-loss exponent, and $s=\sqrt{d^2+h^2}$. In addition, μ_{LoS} and μ_{NLoS} are the attenuation factors for the LoS and NLoS communication links, respectively. Also,

$$F(dB) = \mathbb{P}_{\text{LoS}}h_0 + \mathbb{P}_{\text{NLoS}}h_1. \tag{3}$$

The envelopes of h_0 and h_1 are *Nakagami* distributed, that is, $|h_p| \sim Nakagami(m)$ where $p=\{0,1\}$, and m is the shape parameter which takes the value 1 for Rayleigh fading and any value for h_0 depending on the environment. Hence, the received power at i^{th} SCBS from j^{th} UAV is, written as $\Omega^j_{r_i}(dB) = \Omega^j_t - \Lambda$, where Ω^j_t is the total transmitted power of j^{th} UAV. The SINR received by the i^{th} SCBS from j^{th} UAV is expressed as

$$\Gamma^j_i = \frac{\Omega^j_{r_i}}{\sum_{v=1,v\neq j}^{M}\Omega^v_{r_i} + \sigma_n^2}, \tag{4}$$

where σ_n^2 is the noise power.

III. Problem Formulation

Consider a downlink scenario in which N SCBSs are downloading the data from the ground core network via M UAVs. We assume that the SCBSs are distributed using *Matern type-I* hard core process [17] with density of ρ per square meter, having a minimum separation of $d_{\min^{SCBS}}$ between them. This formulation results in random distribution of SCBSs in Cartesian coordinates. We need to find the required number of UAVs such that all the SCBSs can be served. For this purpose, suppose that each UAV can accommodate up to maximum of L requests from a total of N SCBSs. Therefore, M can be obtained by

$$M = \left\lceil \frac{N}{L} \right\rceil,$$

where $\lceil . \rceil$ denotes the ceil operator. Let $\mathbf{A}$ be an association matrix, in which, row and column represent the entry of SCBSs and UAVs, respectively. Let $a_{ij} \in \{0,1\}$ denotes the entries of matrix $\mathbf{A}$. In case of connectivity, $a_{ij}=1$, otherwise $a_{ij}=0$. Suppose the demanded data rate of i^{th} SCBS from j^{th} UAV is denoted by r^j_i and therefore, the required bandwidth can be calculated as,

$$w^j_i = r^j_i / \log_2(1+\Gamma^j_i). \tag{5}$$

Now, the objective is to find the optimum location of UAV with a predefined optimum number of UAVs such that total data rate of the overall system can be maximized. Therefore, the optimization problem (heuristic in nature) becomes,

$$\max_{\{a_{ij}\}} \sum_{i=1}^{N}\sum_{j=1}^{M} r^j_i . a_{ij} \tag{6a}$$

s.t.

$$\sum_{i=1}^{N}\sum_{j=1}^{M} r^j_i . a_{ij} \leq R_B, \tag{6b}$$

$$\sum_{i=1}^{N} w^j_i . a_{ij} \leq W_j, \qquad \forall_j \tag{6c}$$

$$\sum_{i=1}^{N} a_{ij} \leq L_j, \qquad \forall_j \tag{6d}$$

$$\Gamma^j_i . a_{ij} \geq \Gamma_{\min}, \qquad \forall_{i,j} \tag{6e}$$

$$\sum_{j=1}^{M} a_{ij} \leq 1, \qquad \forall_i \tag{6f}$$

It can be seen from (6) that the association of SCBSs with UAVs is limited by a number of factors including backhaul data rate R_B, bandwidth available to each UAV W, maximum number of requests that can be accommodated by each UAV L, and minimum SINR $\Gamma_{\min}$ criteria to satisfy the QoS requirements. Lastly, each SCBS is only connected with one UAV.

The solution of the objective function in (6) is obtained using the k-means clustering algorithm [18]. The aim is to split the N SCBSs into k regions on the basis of Euclidean distance. Therefore, the k-means algorithm tries to minimize the distance within the cluster nodes by performing iterations.

Suppose, $\mathcal{N} = \{n_1, n_2, ..., n_N\}$ be a vector representing the N number of SCBSs, k-means partitions the vector $\mathcal{N}$ into k regions represented by $\mathfrak{R} = \{\mathfrak{R}_1, \mathfrak{R}_2, ..., \mathfrak{R}_k\}$ so as to minimize the variance within the region,

$$\boldsymbol{arg}\min_{\mathfrak{R}} \sum_{l=1}^{k}\sum_{\mathcal{N}\in\mathfrak{R}_l} \left\|\mathcal{N} - \boldsymbol{\mu}_{\mathbf{l}}\right\|^2, \tag{7}$$

where $\mu_{\mathbf{l}}$ represents the centroids, which are the optimized positions of UAVs. The above expression minimizes the distance within the region and maximizes outside of the region. Therefore, we place the M UAVs on obtained points for the association problem. The algorithm [14]–[16] for the association problem is summarized in Algorithm 1.

IV. Numerical Results

We consider the area of 16 km^2 in which SCBSs are distributed using *Matern type-I* with density of ρ per square meter and having a minimum distance of $d_{\min^{SCBS}}$ between the neighbors. As a result, 28 SCBSs are retained from this process. Then M UAVs are placed using (7). Now, we assign the data rates randomly from the vector $\mathbf{r}_{SCBS}$ and obtain the results using the algorithm presented in Algorithm 1. The parameters for simulation are listed in Table. I. The results are simulated for three different scenarios.

1) Scenario 1: the priority is given to SCBSs demanding maximum data rate.
2) Scenario 2: we give the priority to those, demanding minimum data rate plus bandwidth.
3) Scenario 3: the priority is given to SCBSs with highest spectral efficiency.

Algorithm 1: Association of SCBSs with UAVs

Input: N, M, L, W, R_B, Γ_i^j, r_i^j, w_i^j
Output: $\mathbf{A}$
Initialize: $\mathbf{A} = \emptyset$
for $i = 1$ ***to*** N **do**
  Make a list of UAVs that satify $\Gamma_{\min}$ criterion
  if *Scenario 1* **then**
    Select SCBS having max. data rate
  else if *Scenario 2* **then**
    Select SCBS having $\mathbf{min}(r_i^j + w_i^j)$
  else
    Select SCBS having higher spectral efficiency
for $j = 1$ ***to*** M **do**
  Initialize counters: $T_L = 0$, $T_B = 0$
  while $T_L < L \wedge T_B < W$ **do**
    if $T_B + w_i^j \leq W$ **then**
      Update $\mathbf{A}_{ij} = 1$, T_L =$T_L - 1$ and T_B = T_B + w_i^j
Initialize: T_r as total data rate of associated SCBSs
while $T_r > R_B$ **do**
  Select UAV with min. associated links
  if *Scenario 1 or Scenario 3* **then**
    Select SCBS with min. data rate
  else
    Select SCBS with $\mathbf{max}(r_i^j + w_i^j)$
  De-associate the selected pair and update $\mathbf{A}_{ij} = 0$,
  T_L = $T_L - 1$, T_r = $T_r -$ r_i^j and T_B = $T_B -$ w_i^j

TABLE I
SIMULATION PARAMETERS

Parameter	Value	Parameter	Value
f_c	2 GHz	$\Gamma_{\min}$	-5 dB
β	0.16	σ_n	-125 dB
α	9.61	μ_{LoS}	1 dB
μ_{NLoS}	20 dB	h	300 m
ρ	$2 \times 10^{-6}/\ \text{m}^2$	$d_{\min}^{\text{SCBS}}$	250 m
Area	16 km^2	γ	2
$\mathbf{r}_{\text{SCBS}}$	$\{20, 40, 60, 80, 100\}$ Mbps		

In the considered scenarios, the outcome of Algorithm 1 is investigated for both the approaches (i.e., conventional [14]–[16] and proposed).

Table. II illustrates the performance in terms of associated SCBSs, average bandwidth consumption, sum-rate of overall system, and average link utilization of all four UAVs, for conventional and the proposed approach. Overall, the proposed approach associated the highest number of SCBSs in all scenarios, and conventional approach accommodated lowest. In addition, proposed approach consumed less bandwidth to reach the objective criterion of sum-rate. Moreover, less number of SCBSs experience outage, and the percentage of link utilization is maximum as compared to the conventional approach. In Scenario 1 and 3, both approaches associated less SCBSs as compared to Scenario 2 because the priority was given to higher data rate clients. Similarly, in Scenario 2 of the proposed approach, more requests are served due to the priority of minimum data rate demands. On the other hand, the conventional approach results in serving fewer requests, more bandwidth usage, less link utilization, and more outage of SCBSs. Also, the conventional approach does not achieve objective criteria due to higher bandwidth requirements by each UAV. In Table II, it can also be observed that the proposed approach still needs fewer associations to achieve the objective, therefore, we need to find exact bandwidth requirement and transmitted power to do that, which we deal in the next figure.

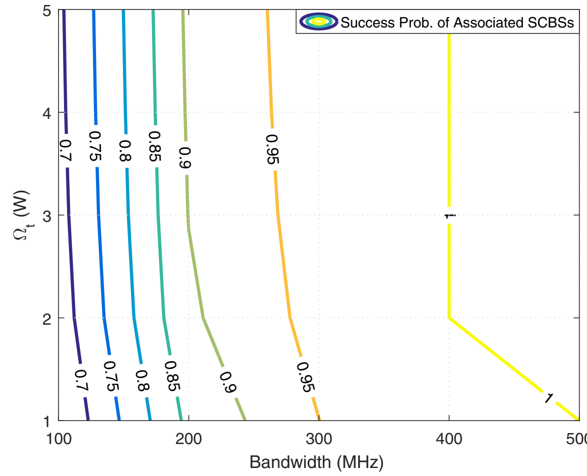

Fig. 2. The contour plot of the success probability of associated SCBSs against Ω_t and W for the proposed approach with constraints $R_B = 1.7$ Gbps, and $L = 11$ averaged over 1000 iterations. (Approach 2)

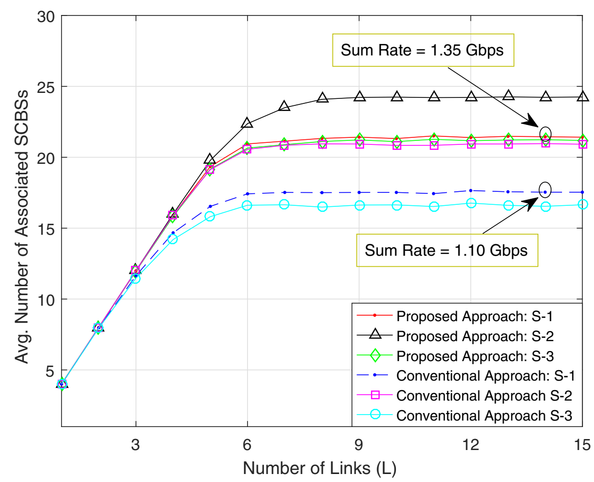

Fig. 3. Number of Links vs Average Associated SCBSs with constraints $R_B = 1.4$ Gbps, $\Omega_t = 1.3$ W, and $W = 200$ MHz averaged over 1000 iterations for all scenarios.

Fig. 2 depicts the success probability of association for

TABLE II
COMPARISON OF RESULTS WITH CONSTRAINTS $R_B = 1.4$ GBPS, $\Omega_t = 1.3$ W, AND $W = 200$ MHZ AVERAGED OVER 100000 ITERATIONS.

Evaluation Parameters	**Conventional Approach**			**Proposed Approach**		
	S-1	**S-2**	**S-3**	**S-1**	**S-2**	**S-3**
Total Associated SCBSs	17	20	16	21	23	21
Avg. BW Consumption (MHz)	181.21	161.13	183.53	162.43	153.44	165.61
Sum-Rate (Gbps)	1.08	1.01	1.04	1.36	1.24	1.34
SCBSs in Outage	11	8	12	7	5	7
Avg. Link Utilization (%)	60.71	71.42	57.14	75	82.14	75

different combinations of transmitted power and required bandwidth. It can be noticed from the figure that the increase in transmission power does not increase the number of associations. In contrast, the increase in bandwidth increases the success probability of association. It can be seen that 100% success probability is achieved at 1.5 W of transmission power and at 475 MHz bandwidth consumption.

Finally, Fig. 3 reveals the performance of both approaches for all scenarios when the number of links are increased from 1 to 15. It can be concluded that the increase in the number of links leads to more SCBSs' associations for both approaches. However, the proposed approach outperforms the conventional one. For example, for $L = 14$, Scenario 1 of proposed approach associates 22 SCBSs whereas conventional approach associates 17, for the same scenario. Also, sum-rate is maximized for the proposed approach as compared to the conventional approach. Moreover, it can be observed that scenario 2 has served more requests in both approaches because of minimum data rate demands.

In summary, it can be deduced from the above results that proposed approach associates more SCBSs by consuming less bandwidth. In 5G+ networks, available bandwidth resources will be limited and hence, by keeping in view the bandwidth usage, our approach gives best results.

V. CONCLUSION AND FUTURE WORK

In this paper, we address the efficient placement of UAVs to provide backhaul connectivity to ground SCBSs with the ground core network. The association of these SCBSs with the UAVs is limited by a number of factors including backhaul data rate limit, number of requests that each user can accommodate, bandwidth available to each UAV, and minimum SINR criterion to meet QoS requirements. Further, the association is done based on three different demands: maximum data rate, minimum data rate plus bandwidth, and higher spectral efficiency. By considering the distribution of SCBSs, the proposed optimum placement of UAVs results in serving more requests by using less bandwidth, and good utilization of links by keeping in mind the objective function as compared to the existing approach presented in the literature. In future, we will also consider the age of information and hover time of UAV in the list of communication constraints. Also, stochastic geometry of association problem will be addressed. While the optimum placement of UAV will be investigated by considering energy efficiency.

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