Learn-As-You-Fly (LAYF): A Distributed Algorithm for Joint 3D Placement and User Association in Multi-UAVs Networks

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Objective

The objective is to efficiently place the UAVs in the 3D plan and associate the users in order to reach an efficient value of the downlink sum-rate of the network.

- The majority of existing works either consider a single UAV or assume an interference-free environment [1].
- Moreover, they typically set up centralized algorithms to reach the best network performance [2].

Three challenges to address:

1. Optimize the 3D placement in a way that reduces interference and increases the aggregate rate.
2. Associate the users while satisfying their QoS, and respecting the maximum bandwidth of UAVs.
3. Design a distributed algorithm that, when implemented on UAVs, achieves reliable solutions.

Problem Formulation

\[
\max_{x_i,y_i,h_i} \sum_{i=1}^{I} x_i y_i h_i
\]

s.t. \(x_i^\text{min} \leq x_i \leq x_i^\text{max}, y_i \in \mathbb{R}, h_i \in \mathbb{R} \)

\(x_i^\text{min} \leq y_i \leq x_i^\text{max}, y_i \in \mathbb{R}, h_i \in \mathbb{R} \)

\(x_i^\text{min} \leq h_i \leq x_i^\text{max}, y_i \in \mathbb{R}, h_i \in \mathbb{R} \)

\(a_i \in \{0,1\}, x_i \in \mathbb{R}, h_i \in \mathbb{R} \).

The problem is mathematically challenging as it involves: a non-convex objective function, and non-convex and non-linear constraints.

The underlying optimization problem is a mixed integer non-linear programming (MINLP).

It is, moreover, NP-hard (due to the users-UAVs association that can be formulated as the well-known knapsack problem).

Requested data rate

\[ R_i = h_i \log_2(1 + \frac{g_i^2 d_i^2}{\sigma_i^2 + \sum_{j \neq i} g_j^2 d_j^2}) \] (2)

Path Loss

\[ L_i(d_i) = \left(\frac{4\pi d_i}{c}\right)^2 \left(\frac{1}{h_i} + \frac{1}{h_j}ight)^2 \] (3)

Approach

We propose an algorithm referred to as Learn-As-You-Fly (LAYF) that iteratively breaks the underlying optimization problem into three subproblems: 2D UAVs positioning, the altitude optimization, and the users-UAVs association.

1. Users-UAVs association: a distributed matching scheme that allocates the bottlenecks of the bandwidth and guarantees the required quality of service.
2. 2D UAVs positioning: the 2D coordinates are updated using a modified K-means approach where UAVs dynamically change their 2D positions in order to reach the barycenter of the served ground users.
3. Altitude optimization: UAV altitudes are adjusted by only optimizing a local utility function using best-response dynamics.

Simulation Results

Figure: 3D configuration with UAVs trajectories for LAYF approach compared with LAYF-Nearest and centralized approaches.

Figure: (a) Algorithms convergence (b) Bandwidth effect.