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

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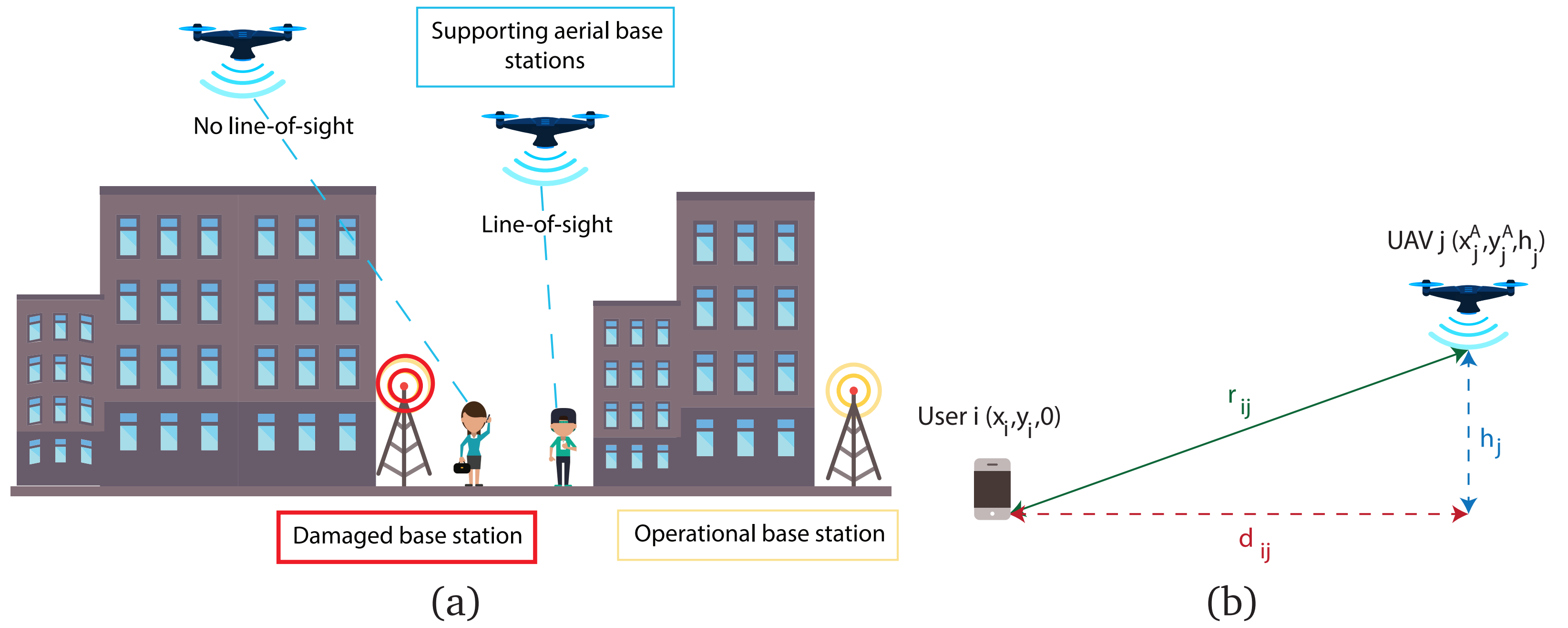
Objective

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].



(a) (b)

Figure: (a) System model, (b) distances notations.

- 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

$$\begin{array}{lll}
\max_{\mathbf{A},(\mathbf{x}^A,\mathbf{y}^A,\mathbf{h})} & \sum_{j\in\mathcal{B}^A}\sum_{i\in\mathcal{U}} a_{ij}R_i & \\
\text{s.t.} & R_i = b_{ij}\eta_{ij}, i\in\mathcal{U}, & \forall j\in\mathcal{B}^A \\
& \sum_i a_{ij}b_{ij} \le B_j, & \forall j\in\mathcal{B}^A \\
& \frac{a_{ij}}{\eta_{ij}} \le \frac{1}{\eta^{\min}}, & \forall (i,j)\in\mathcal{U}\times\mathcal{B}^A \\
& x^{\min} \le x_j^A \le x^{\max} & \forall j\in\mathcal{B}^A \\
& y^{\min} \le y_j^A \le y^{\max} & \forall j\in\mathcal{B}^A \\
& h_j \in \mathcal{H} & \forall j\in\mathcal{B}^A \\
& \sum_j a_{ij} \le 1, & \forall i\in\mathcal{U} \\
& a_{ij}\in\{0,1\}, & \forall (i,j)\in\mathcal{U}\times\mathcal{B}^A.
\end{array} \quad (1)$$

- 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

$$R_i = b_{ij}\mathbb{E}_{\mathbf{g}}\Big[\log_2\Big(1+\frac{g_{ij}L(r_{ij},d_{ij})P_j}{\sigma^2+\sum_{j\neq k} g_{ik}L(r_{ik},d_{ik})P_k}\Big)\Big]. \quad (2)$$

Path Loss

$$L_{ij}(r_{ij},d_{ij})=\left(\frac{4\pi f r_{ij}}{c}\right)^{-\alpha}\left(\zeta_{\text{LoS}}p_{ij}^{\text{LoS}}(r_{ij},d_{ij})+\zeta_{\text{NLoS}}(1-p_{ij}^{\text{LoS}}(r_{ij},d_{ij}))\right)^{-1} \quad (3)$$

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.

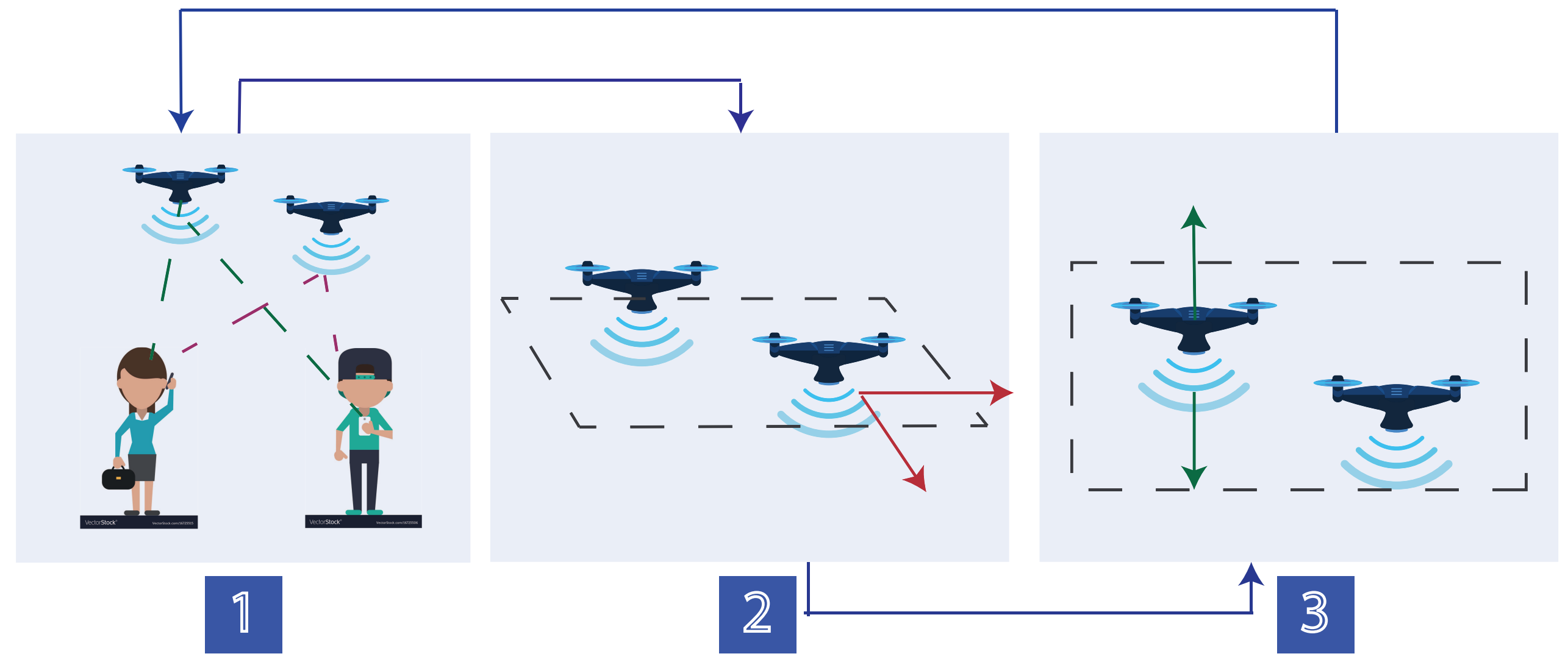
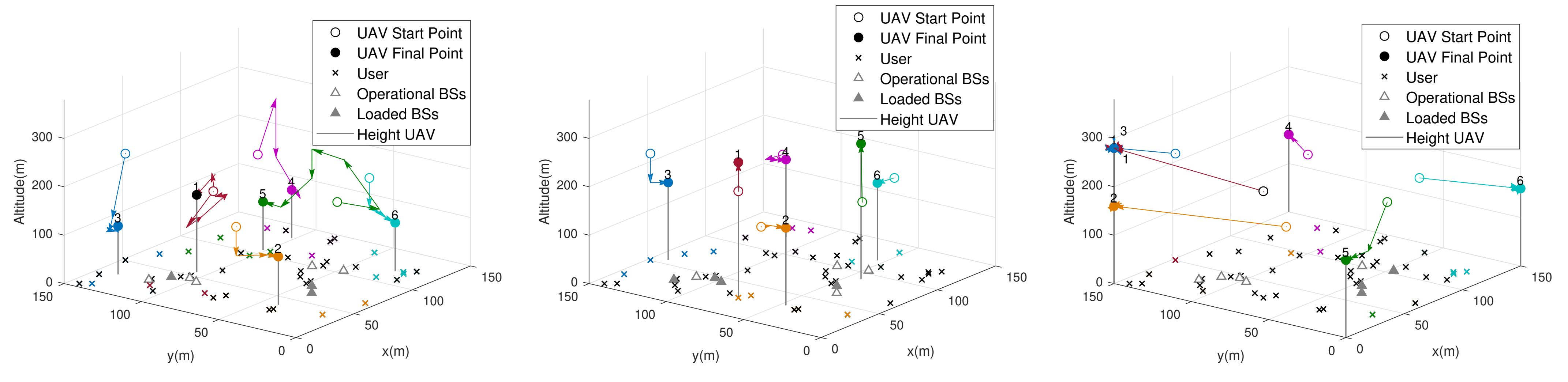


Figure: LAYF breaks the problem into 3 sub-problems.

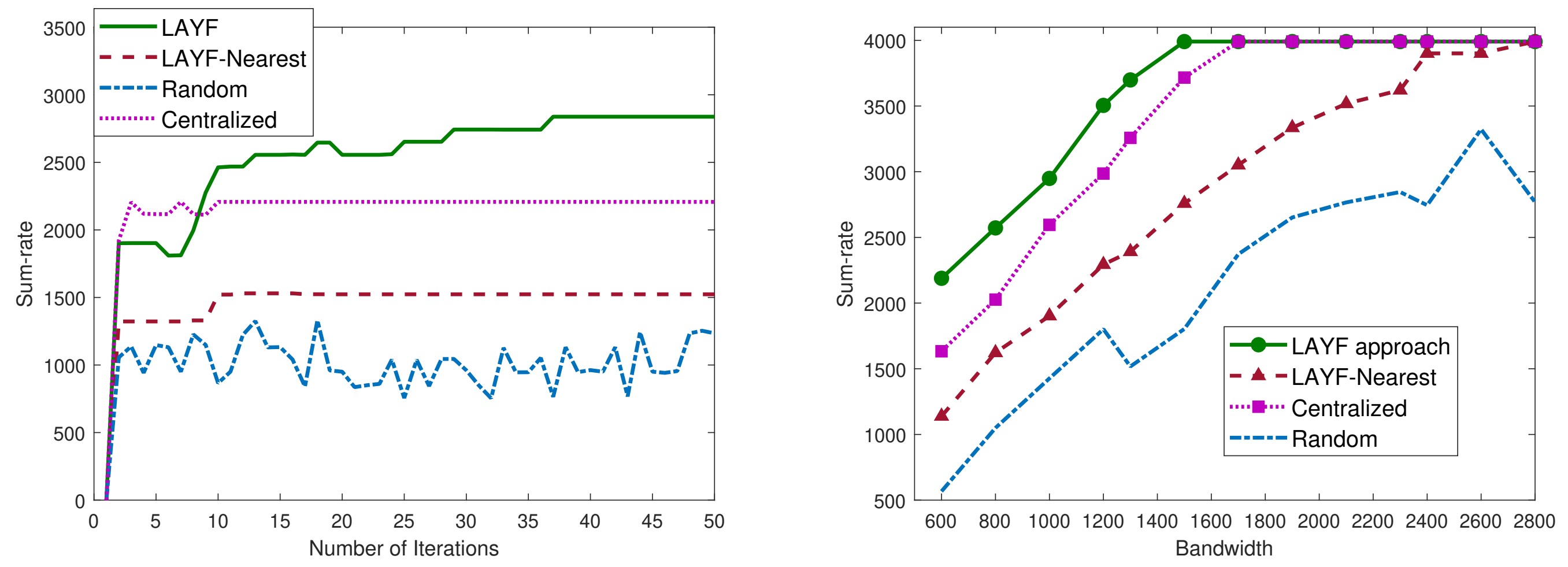
1. Users-UAVs association: a distributed **matching scheme** that alleviates the bottlenecks of the bandwidth and guarantees the required quality of service.
2. 2D UAVs positioning: the 2D coordinates are updated using a modified **K-means** approach where UAVs dynamically change their 2D positions in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

Simulation Results



(a) LAYF (b) LAYF-Nearest (c) Centralized

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



(a) (b)

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

[1] Y. Li *et al.*, "Power allocation and 3-D placement for floating relay supporting indoor communications," IEEE TMC, no. 3, pp. 618â631, 2019.

[2] E. Kalantari *et al.*, "User association and bandwidth allocation for terrestrial and aerial base stations with backhaul considerations," in PIMRC, Montreal, QC, Canada, Sep. 2017.