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Towards Socially-Acceptable Multi-Criteria Resolution of the 4D-Contracts Repair Problem

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The Problem: 4D-CRP

Given a set of UAVs, the *4D-Contract Repair Problem* (or 4D-CRP) amounts to find a set of corrective actions to solve all the conflicts between the trajectories of the UAVs, whilst minimizing the overall cost of the corrective actions

- A *trajectory* ω is a set $W \subset \mathbb{R}^4$ of *4D points* $w = (x, y, z, t)$ where x and y are coordinates on the 2D plane (or GPS coordinates), z is the altitude, and t the time
- *Safety tubes* are volumes defined horizontally (for x and y dimensions), vertically (for z) and timely (for t), by $\tau = (h, v, t)$, around each segment of a trajectory ω, noted $\sigma_\tau(\omega)$
- A *UAV* is defined by a tuple $u = (p, s, d, c, \omega)$, where $p = (x, y, z, t) \in \mathbb{R}^4$ is its position, $s = (h, v, a) \leq (h_{max}, v_{max}, a_{max}) \in \mathbb{R}^3$ represents its current horizontal (in m.s^{-1}), vertical (in m.s^{-1}) and angular (rad.s^{-1}) speeds. $d \in [0, 2\Pi]$ defines its current direction, c is its current state of charge, and ω is its 4D trajectory/contract

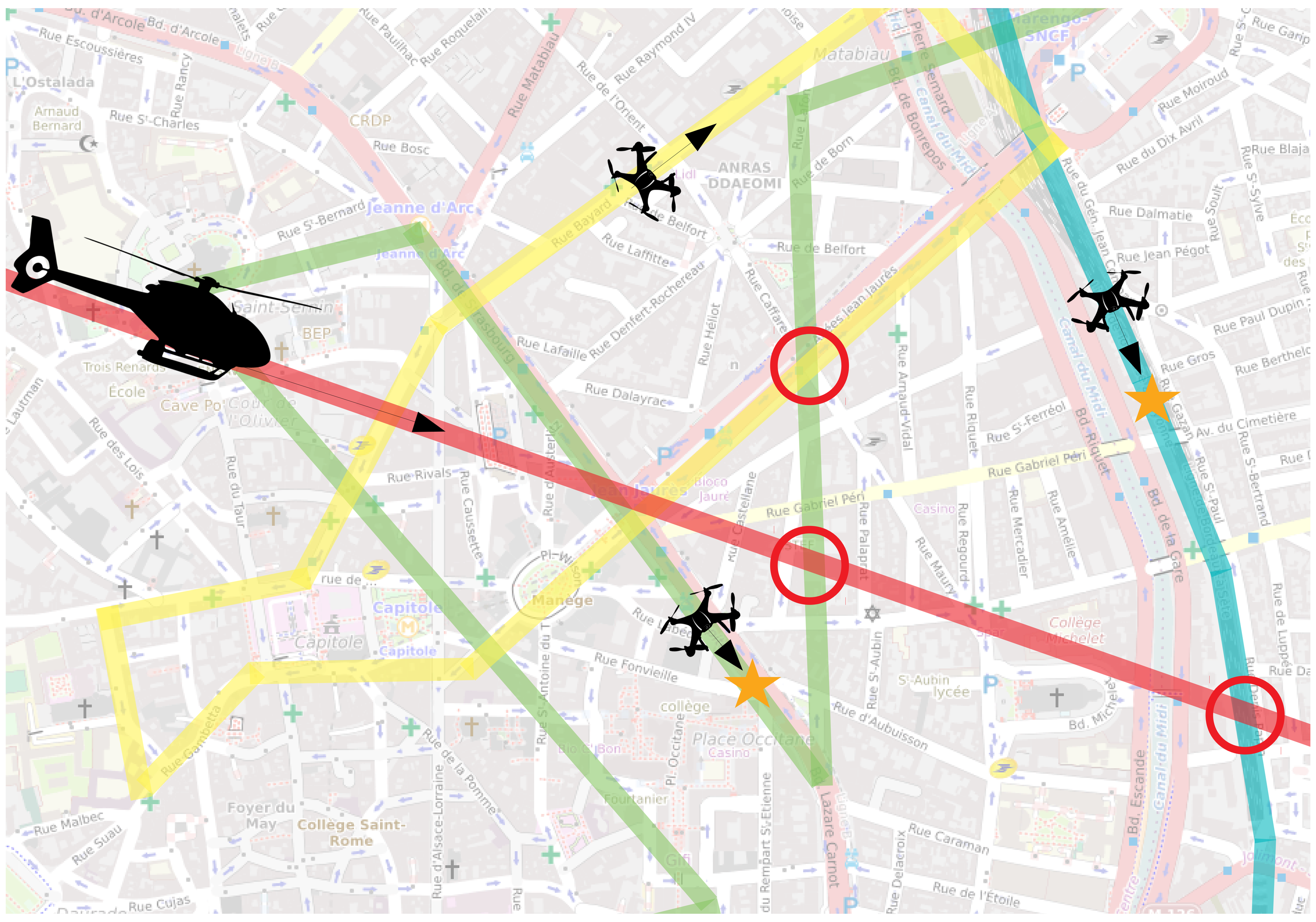

Figure: 3 UAVs following their trajectories (green, blue and yellow) handling some incidents (orange stars), a Medevac helicopter on its emergency trajectory (red), and identified conflicts (red circles), from [2].

Corrective Actions

- Simple and understandable actions to modify trajectories
  - *postpone* (delay waypoints)
  - *elevate* (change altitude to bypass conflicts)
  - *skip* (remove conflicting segment)
- Foster clarity, scalability, and predictability while ensuring safety by maintaining separation between UAVs

Investigated Solution Methods

- *Graph Search*: centralized
- *Sequential Auctions*: distributed, based on SSI [3]
- *Sequential DCOP*: distributed, based on AFB [1]

Action Costs and Concessions

$\kappa_c(a)$: the difference between the initial number of conflict the conflicts in the resulting set of trajectories

$\kappa_b(a)$: the energy consumption resulting from performing action a

$\kappa_d(a)$: the delay resulting from performing the action a

$\kappa_w(a)$: the number of missed waypoints, i.e. 1 for *skip*, 0 otherwise.

$\overline{\kappa_b}(u)$: the total energy conceded

$\overline{\kappa_d}(u)$: the total delay conceded

$\overline{\kappa_w}(u)$: the total number of withdrawn waypoints

$\Rightarrow$ Lexicographically ordered (e.g. guarantee safety before QoS)

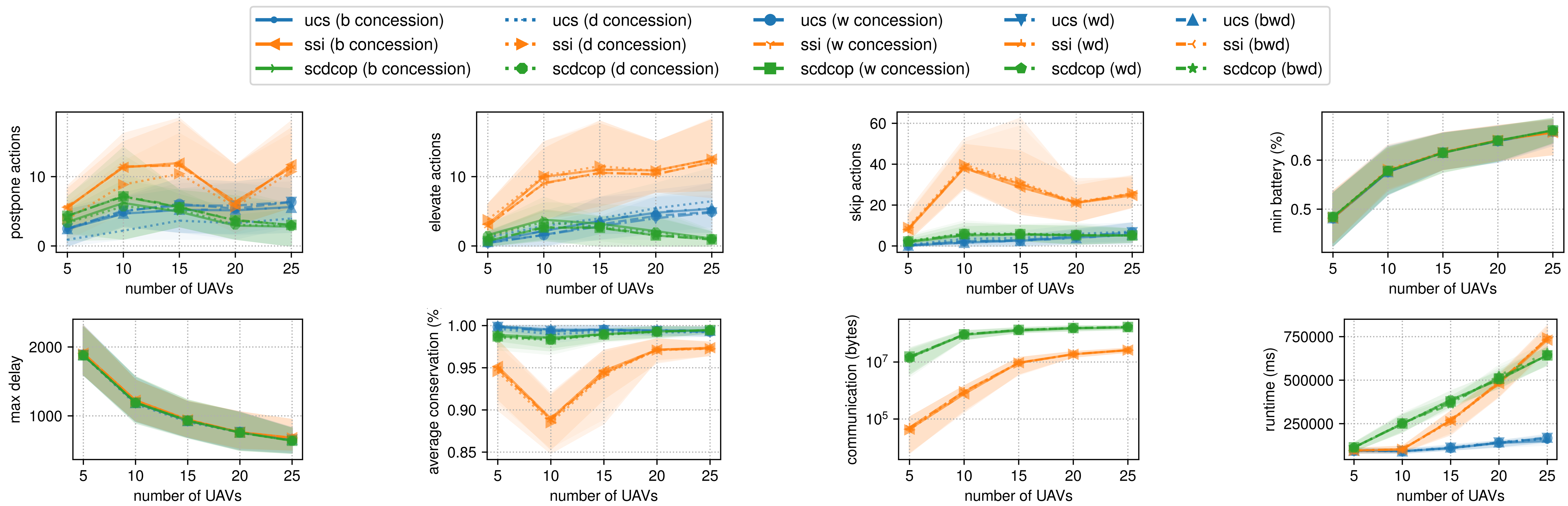

Figure: Average values over 30 instances for several performance metrics with increasing number of UAVs.

[1] A. Gershman, A. Meisels, and R. Zivan. Asynchronous forward bounding for distributed cops. *J. Artif. Int. Res.*, 34(1):61–88, 2009. ISSN 1076-9757.

[2] Gauthier Picard. Trajectory coordination based on distributed constraint optimization techniques in unmanned air traffic management. In *International Conference on Autonomous Agents and Multiagent Systems (AAMAS-22)*, pages 1065–1073. IFAAMAS, 2022. doi: https://dl.acm.org/doi/10.5555/3535850.3535969.

[3] Adrian Schoenig and Maurice Pagnucco. Evaluating sequential single-item auctions for dynamic task allocation. In Jiuyong Li, editor, *AI 2010: Advances in Artificial Intelligence*, pages 506–515, Berlin, Heidelberg, 2011. Springer Berlin Heidelberg. ISBN 978-3-642-17432-2.

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