Safe Optimistic Path Planning for Autonomous Drones under Dynamic Energy Costs

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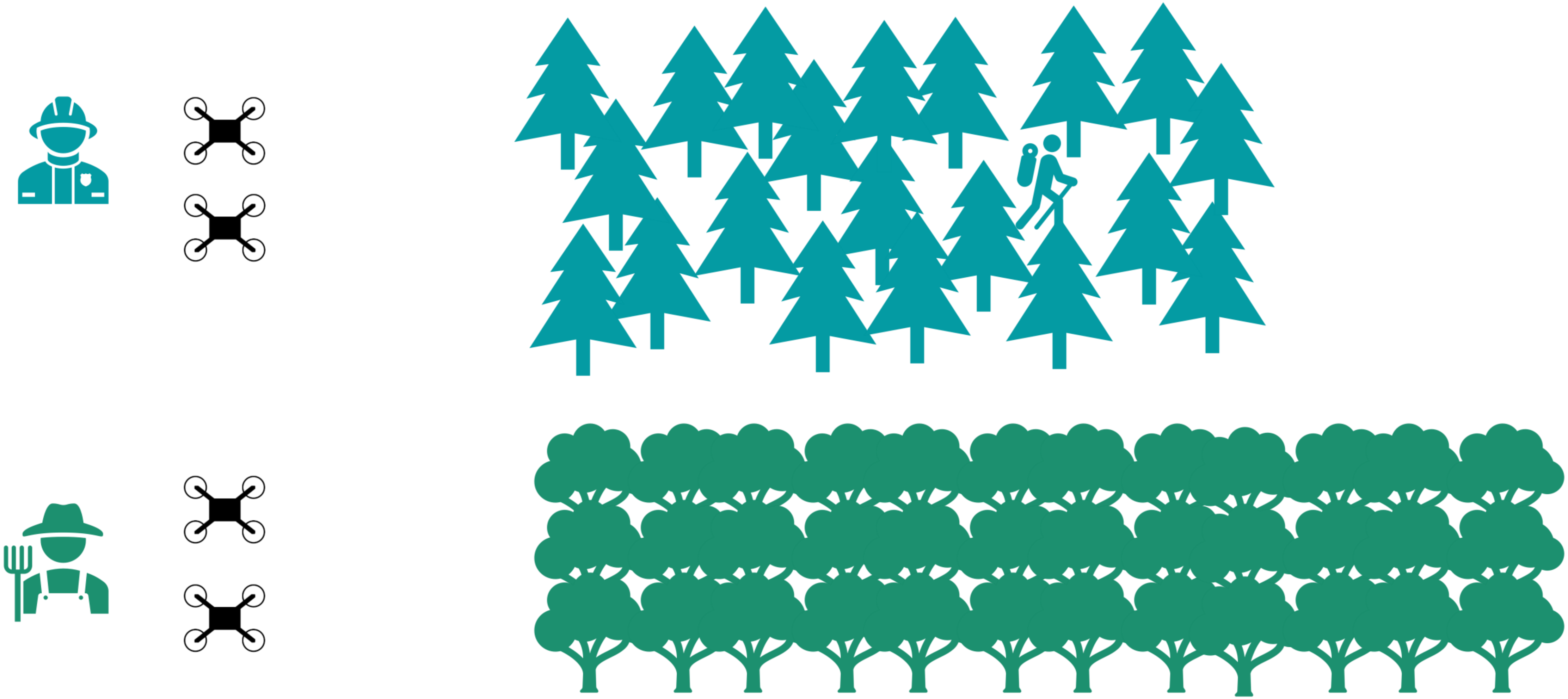
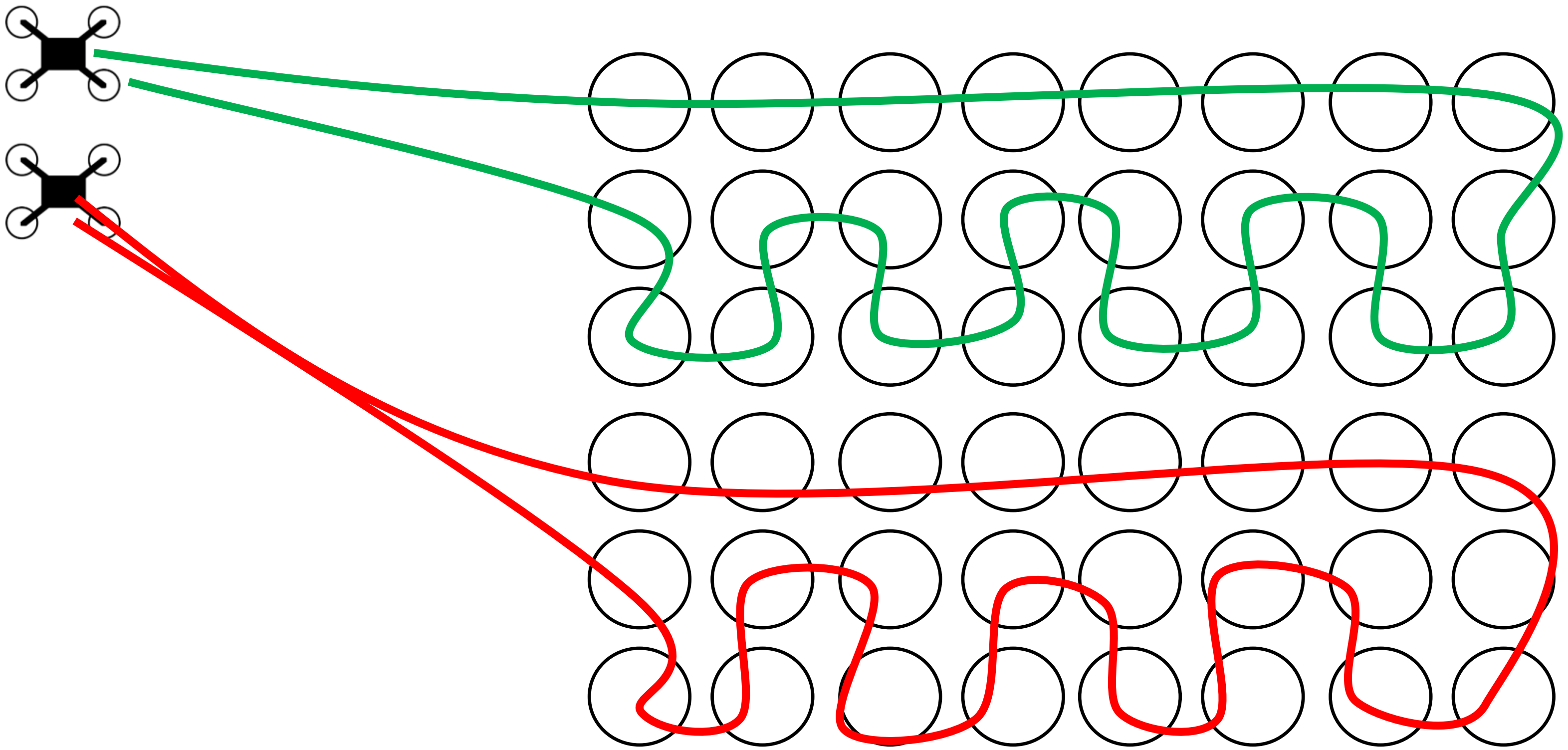
Co-financed by Greece and the European Union

- Motivation
- Problem formulation
- Approach
- Experiments and results
- Conclusion

Application scenarios



The problem



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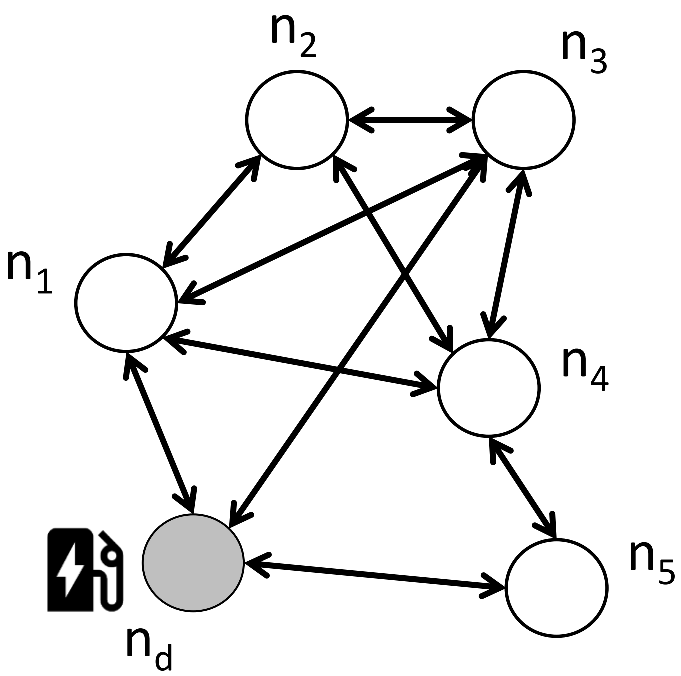
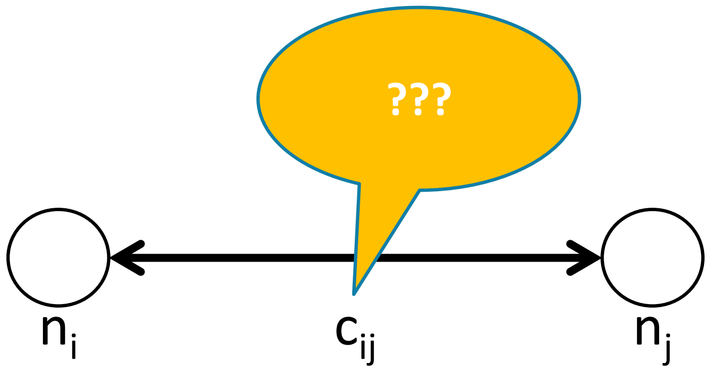
Terrain

- $G = (N,E)$
- N is the set of nodes
  - n_i is a target
  - n_d is a depot node
- E is the set of edges
  - e_{ij} is the edge between n_i and n_j



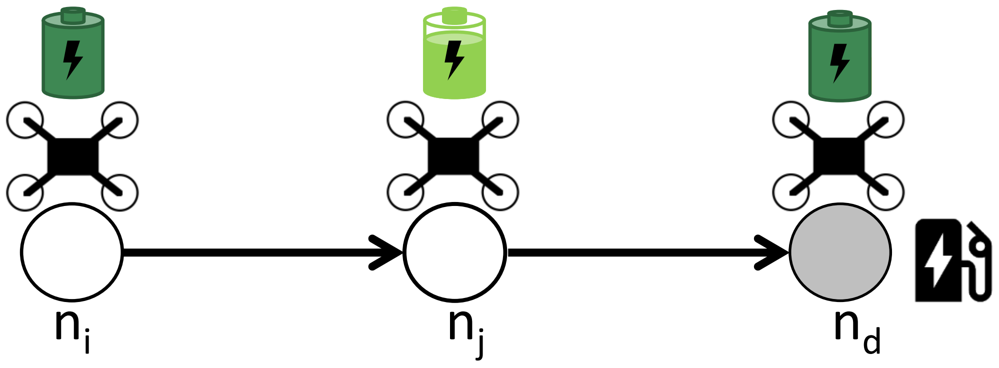
Edge cost

- Let $c_{ij} > 0$ be the cost of edge e_{ij}, corresponding to the energy/fuel that is required to cross e_{ij}
- The exact edge costs are **unknown** a priori (before crossing an edge)
- During planning, c_{ij} is **estimated** based on its random distribution



Energy: capacity - consumption - gain

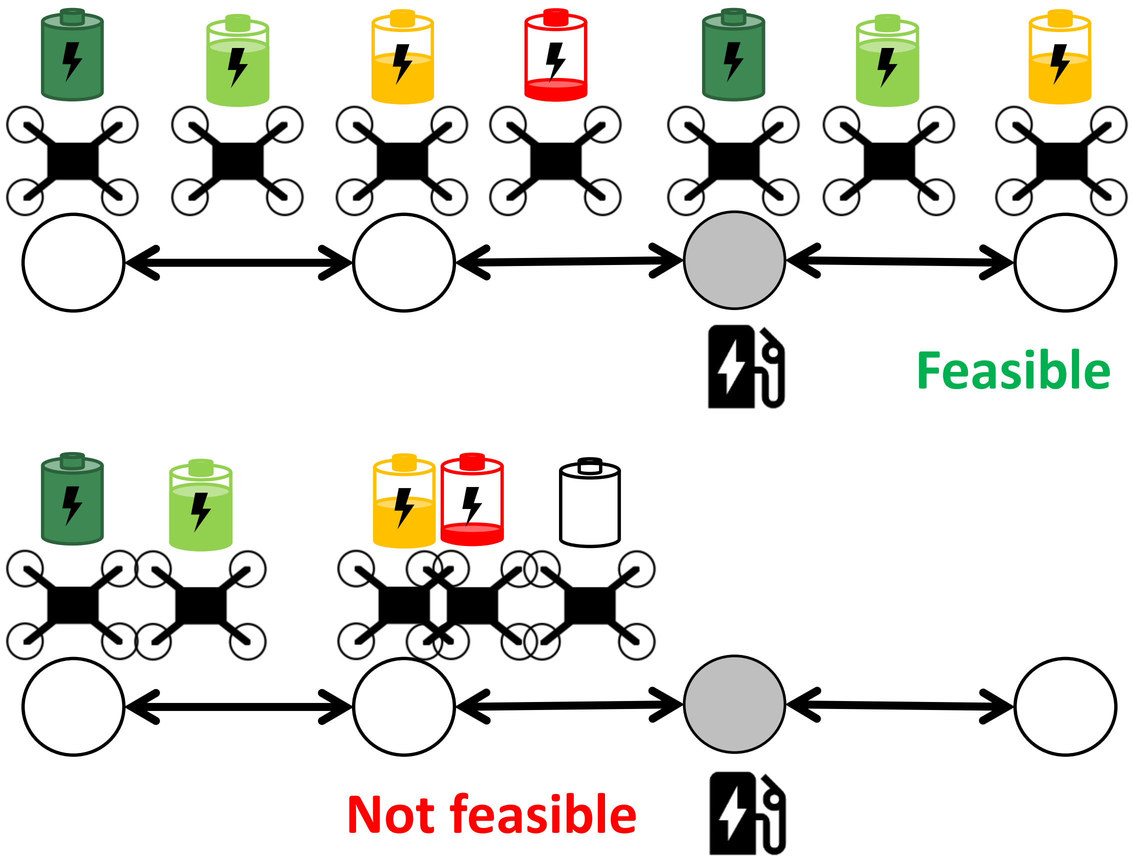
- Each vehicle has maximum energy capacity B_{MAX}
- The energy decreases according to the edge cost
- Vehicles can refuel/change batteries in the depot nodes



Path feasibility

- A path is a sequence of nodes

- A path is feasible if the energy of the vehicle is not exhausted in any point of the path

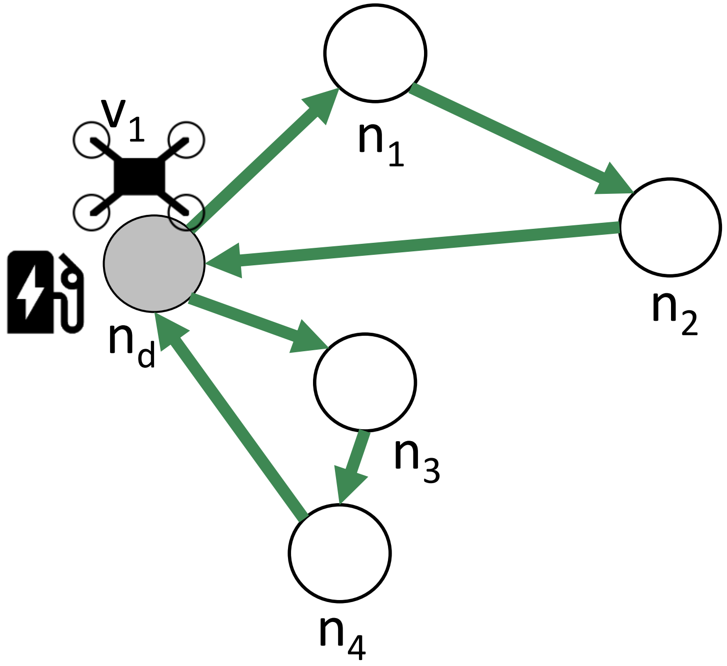


Vehicle makespan

- Let *travel*(c_{ij}) = t_{ij} be the time needed to cross the edge e_{ij}

- Let the makespan of one vehicle be the sum of the travel times of the edges in its paths

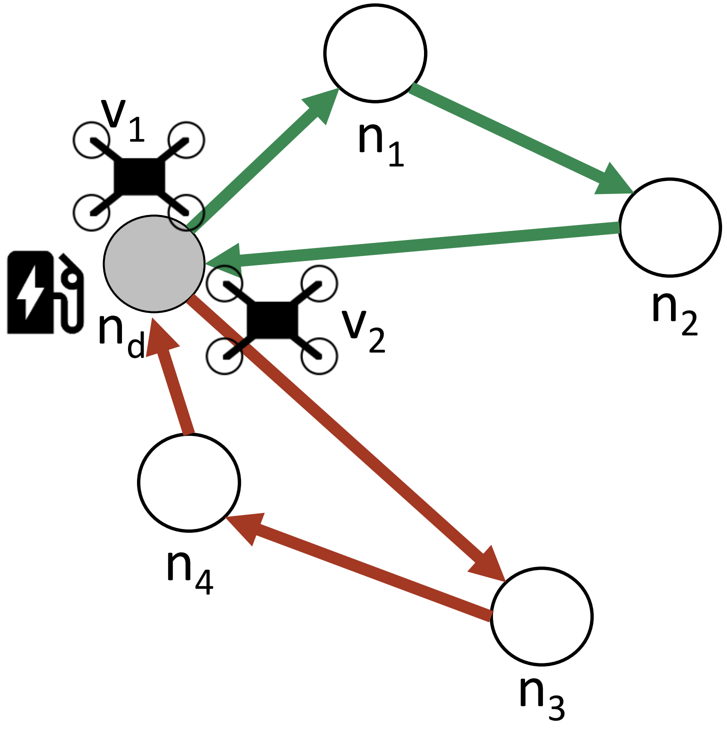
- $makespan_{v1} = t_{d,1} + t_{1,2} + t_{2,d} + t_{d,3} + t_{3,4} + t_{4,d}$



Mission makespan

- Let the mission's makespan be the maximum makespan of all vehicles

- *makespan* = $max(makespan_{v1}, makespan_{v2}) = max(t_{d,1}+t_{1,2}+t_{2,d}, t_{d,3}+t_{3,4}+ t_{4,d})$



Objective

Given M vehicles and a set of nodes of interest, find a feasible schedule (paths) so that:

1. All nodes are visited
2. No vehicle exhausts its energy (all vehicles return safely to the starting depot node)
3. The mission's makespan is minimized

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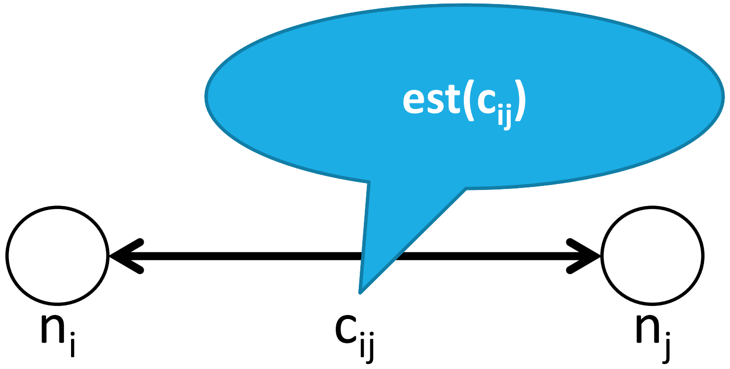
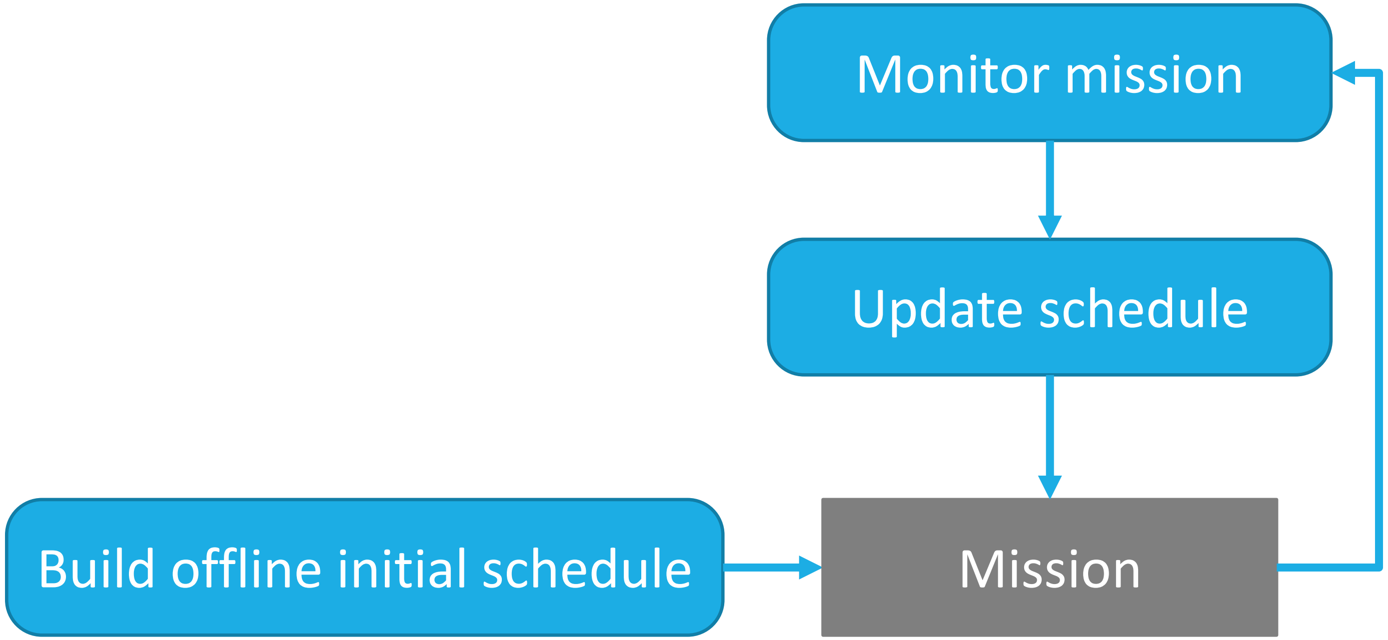
Edge cost estimation

- Configurable
- Assume function $est(c_{ij}) < c_{ij}^{max}$



High level concept

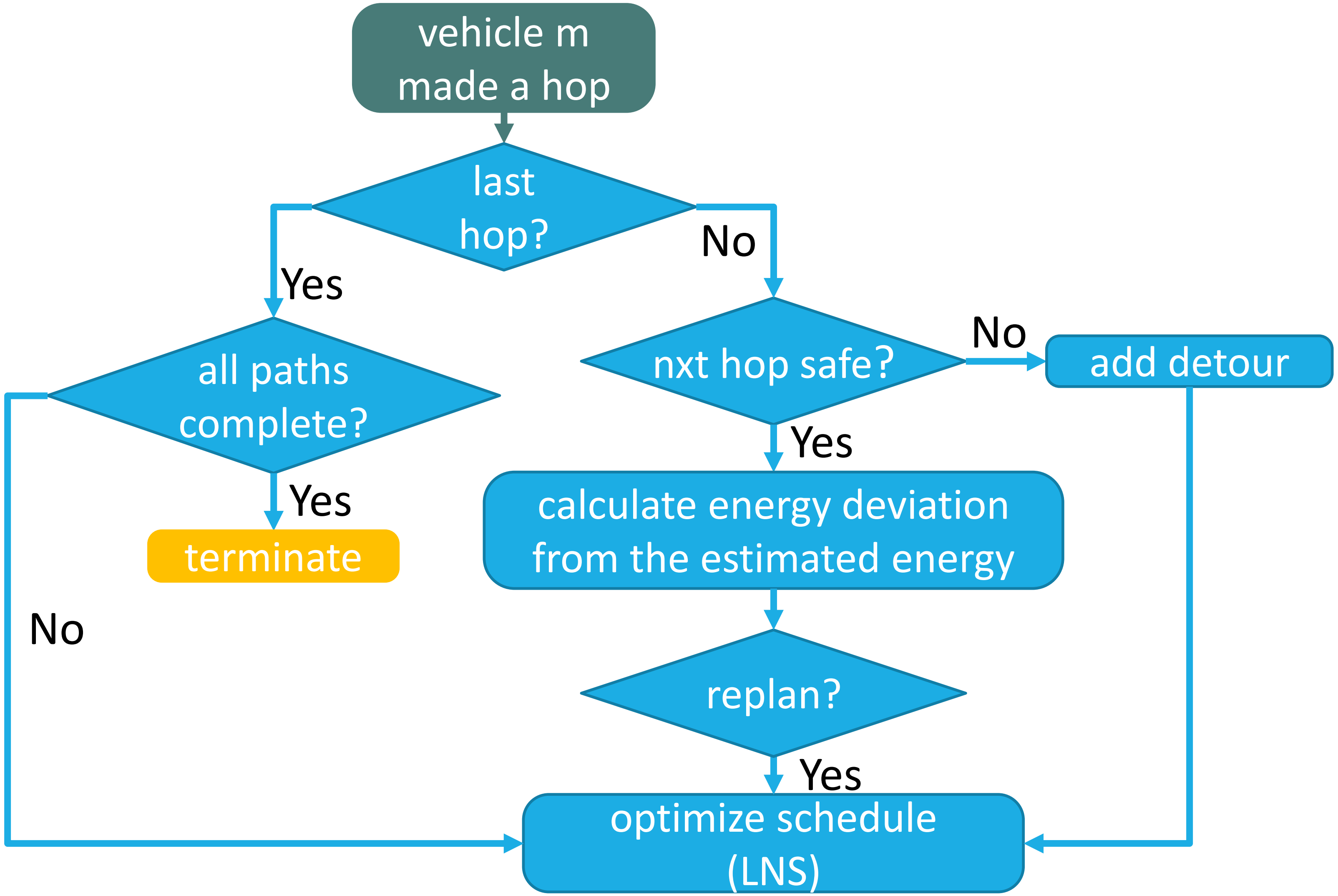


Main control loop

$energy_{current} - c_{i,j}^{max} - c_{j,d}^{max} > 0$:

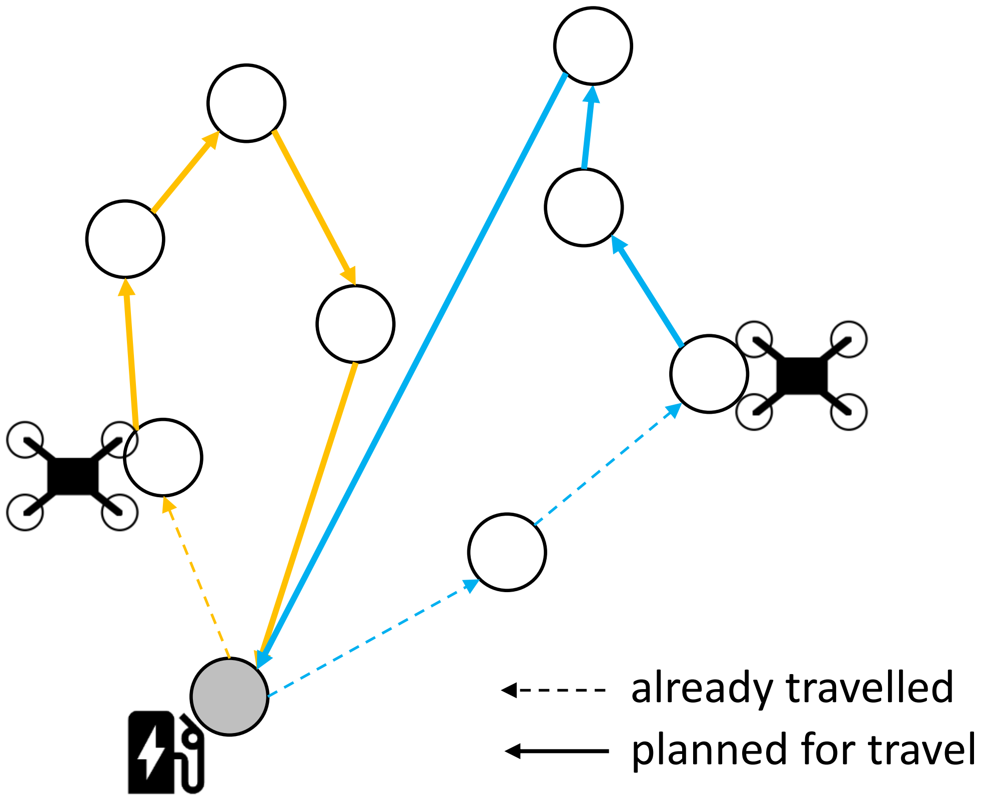
- n_i the current node
- n_j the next node

Deviation > Threshold



Path re-planning

- For path re-planning we use Large Neighborhood Search (LNS)
- Two-step procedure

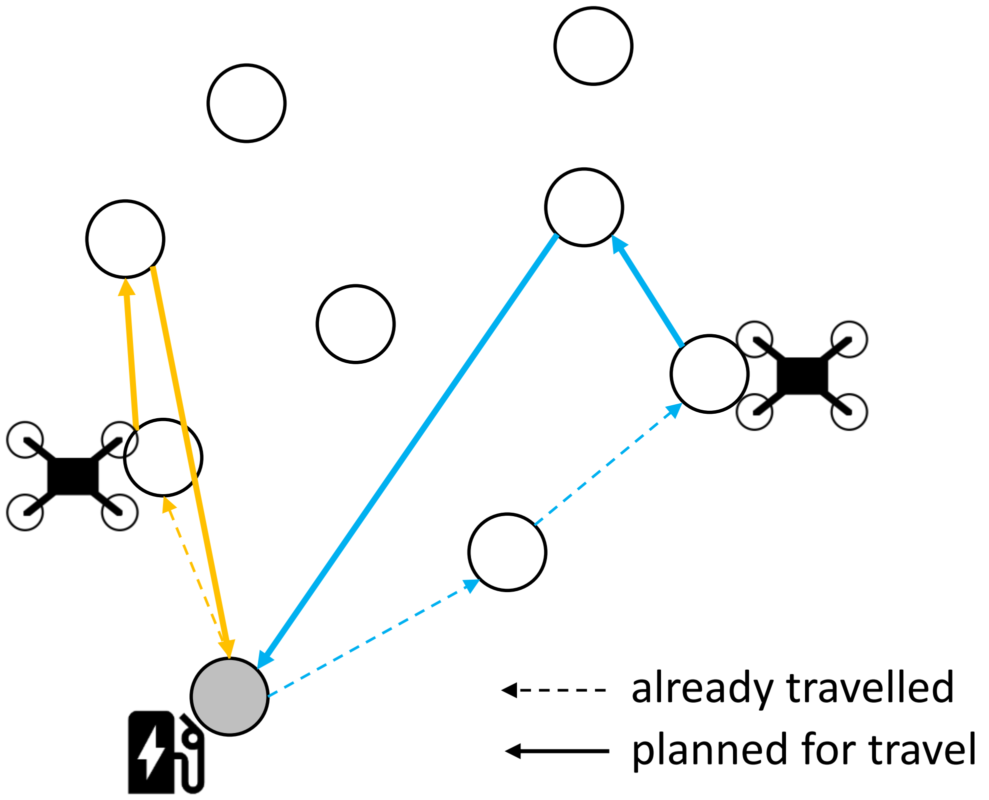


Path re-planning

- For path re-planning we use Large Neighborhood Search (LNS)

- Two-step procedure

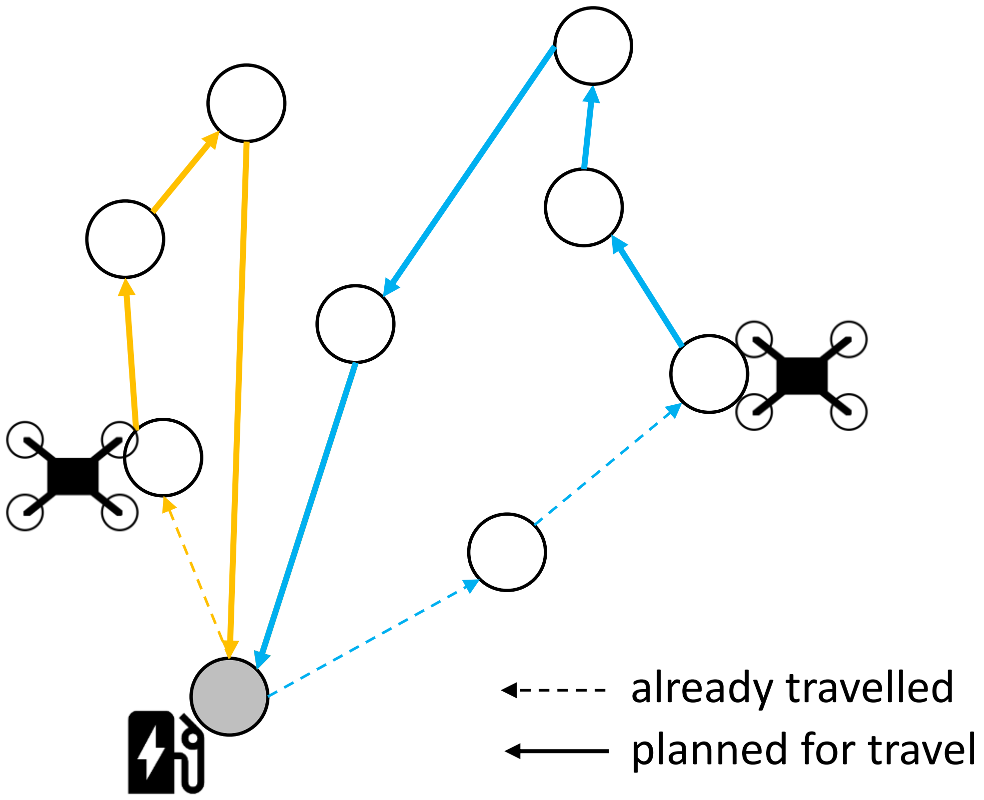
1. Remove nodes



Path re-planning

- For path re-planning we use Large Neighborhood Search (LNS)
- Two-step procedure

1. Remove nodes
2. Re-insert nodes



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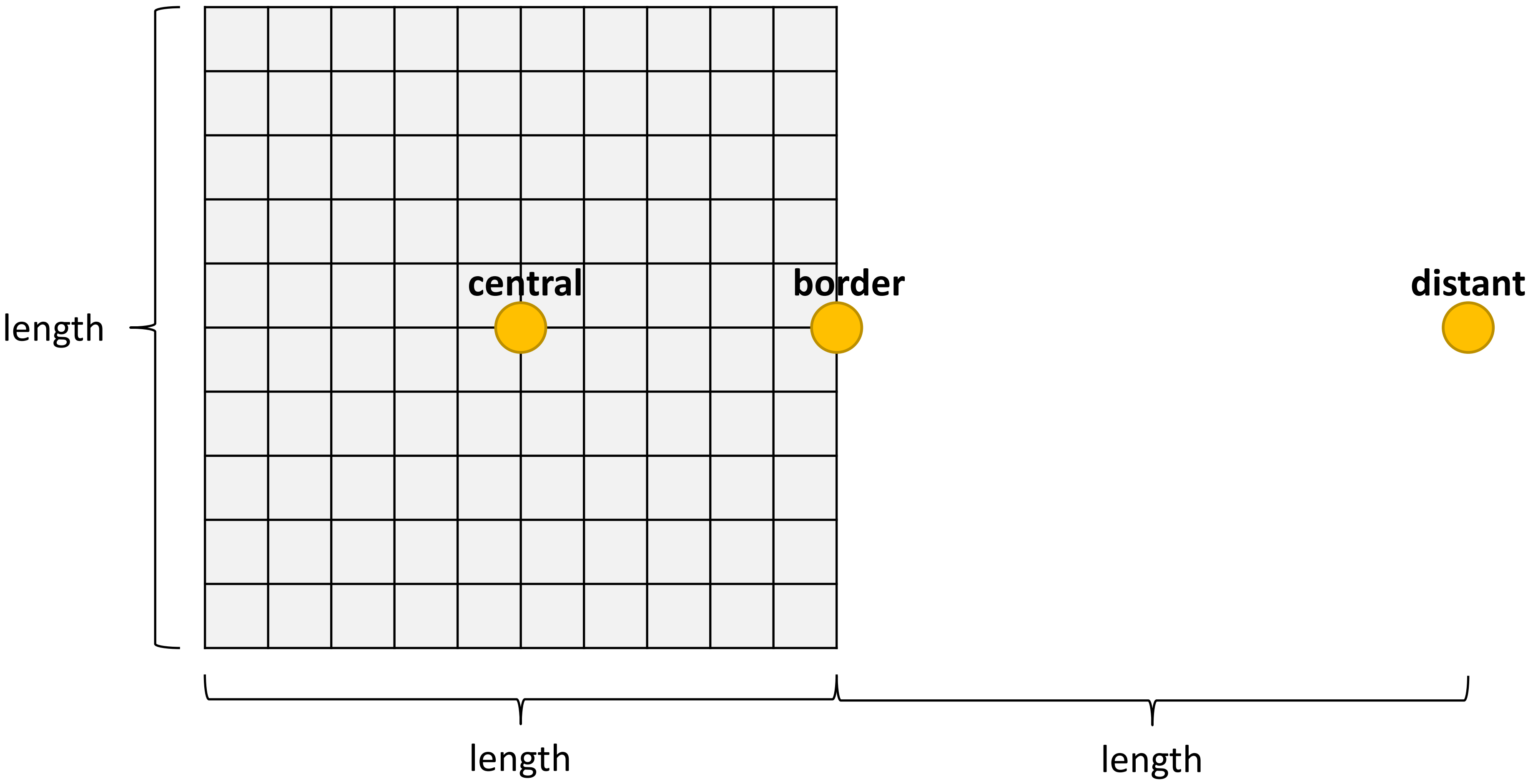
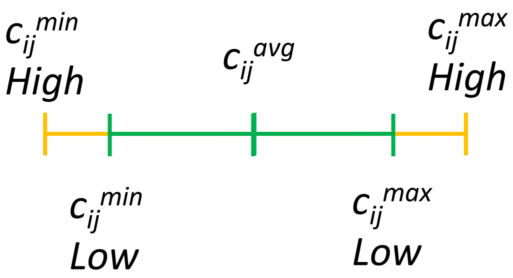
Parameters: topology

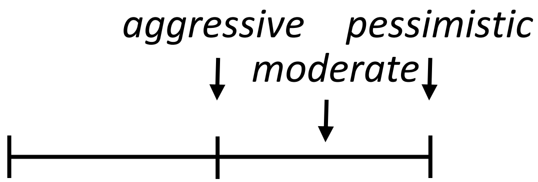


Parameters: cost, optimism, fleet size

- Travel costs
  - c_{ij} follows uniform distribution [c_{ij}^{min}… c_{ij}^{max}]
  - c_{ij}^{avg} = EuclideanDist(n_i,n_j)
  - **Low uncertainty:** $c_{ij}^{min} = 3/4 * c_{ij}^{avg}$ and $c_{ij}^{max} = 5/4 * c_{ij}^{avg}$
  - **High uncertainty:** $c_{ij}^{min} = 2/3 * c_{ij}^{avg}$ and $c_{ij}^{max} = 4/3 * c_{ij}^{avg}$



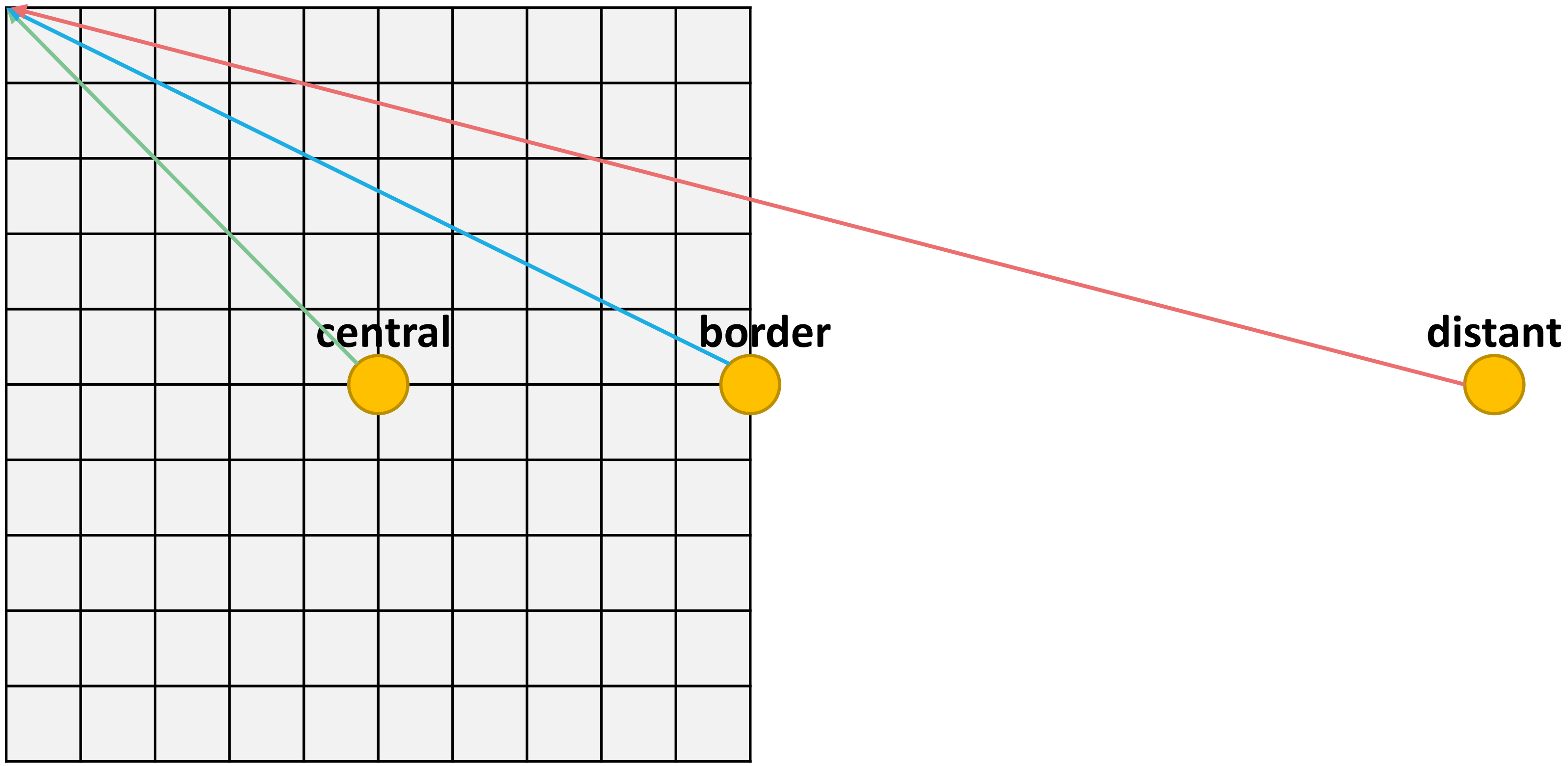
- Degree of optimism
  - **Aggressive:** $est(c_{ij}) = c_{ij}^{avg}$
  - **Moderate:** $est(c_{ij}) = (c_{ij}^{avg} + c_{ij}^{max})/2$



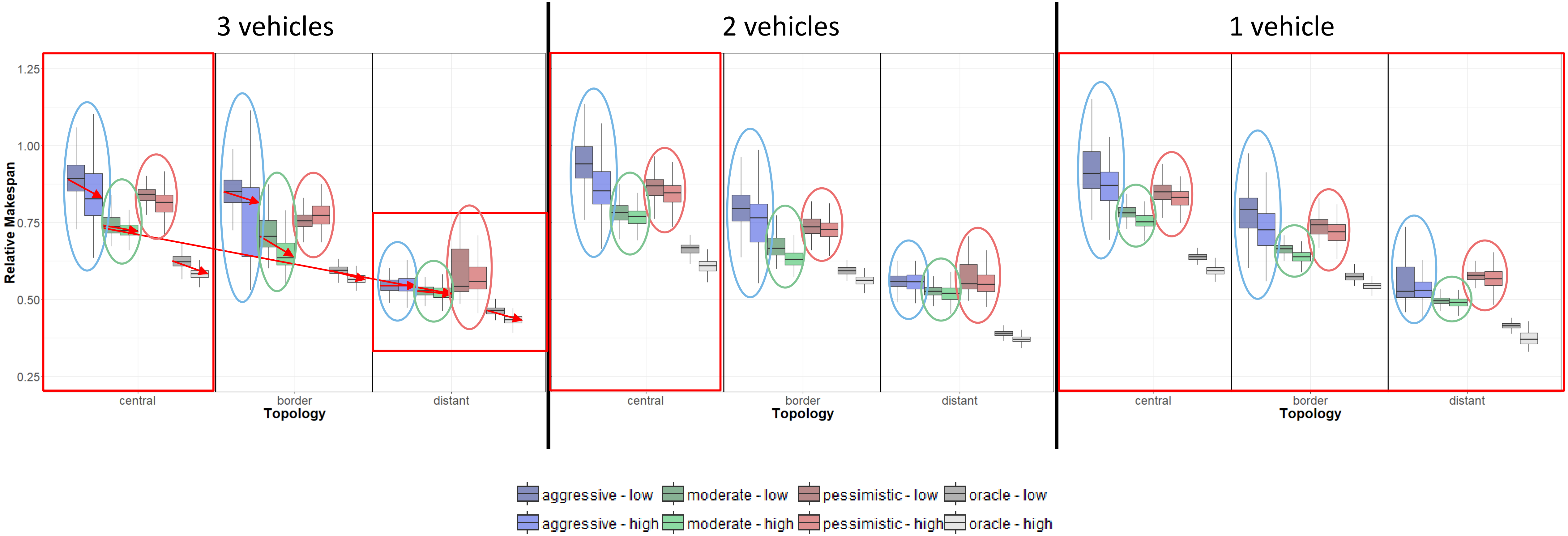
- Fleet
  - **3** vehicles
  - **2** vehicles
  - **1** vehicle

Maximum energy capacity

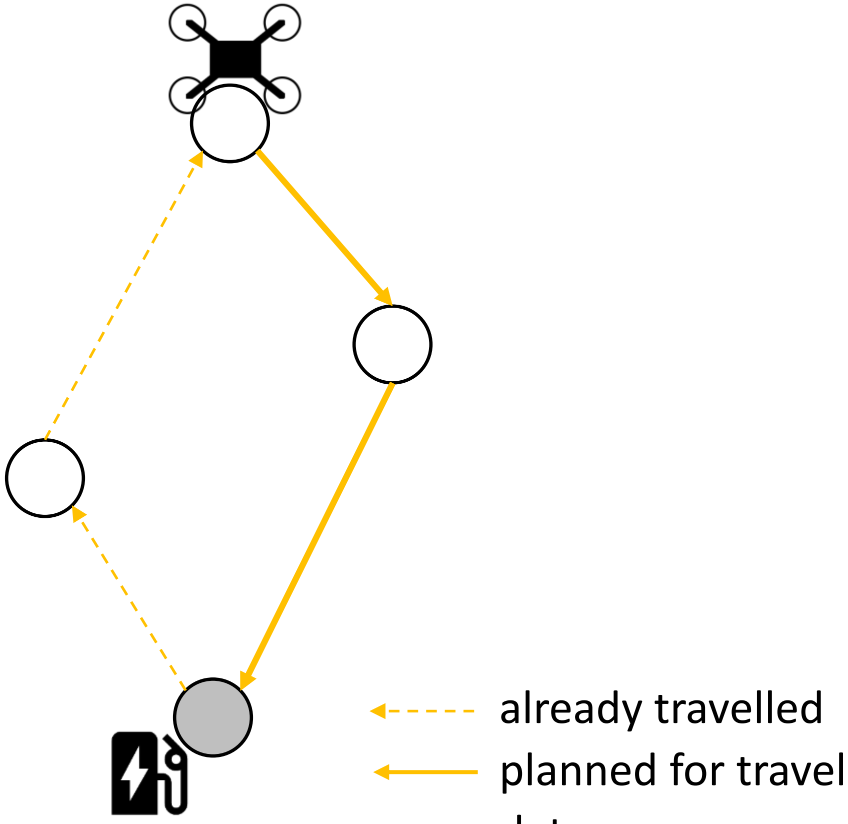
Vehicle's energy capacity = worst-case round-trip cost



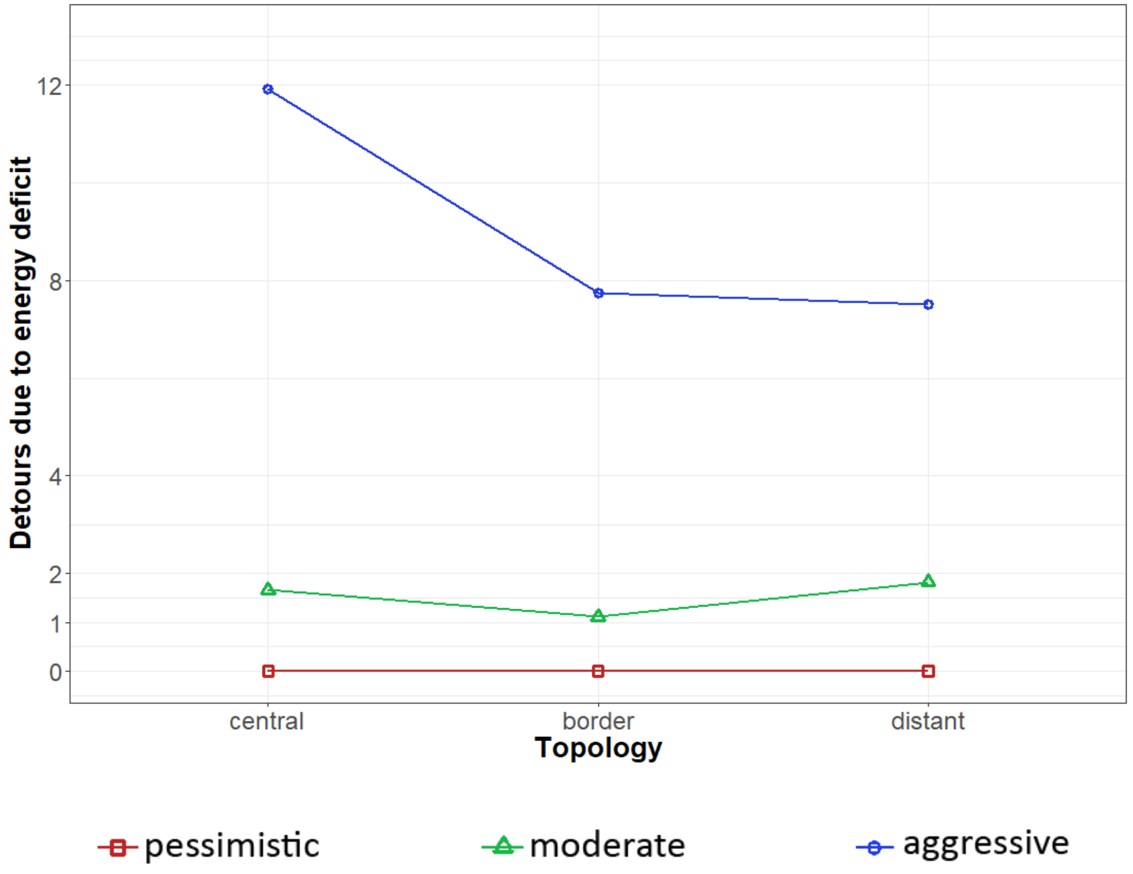
Results: relative makespan

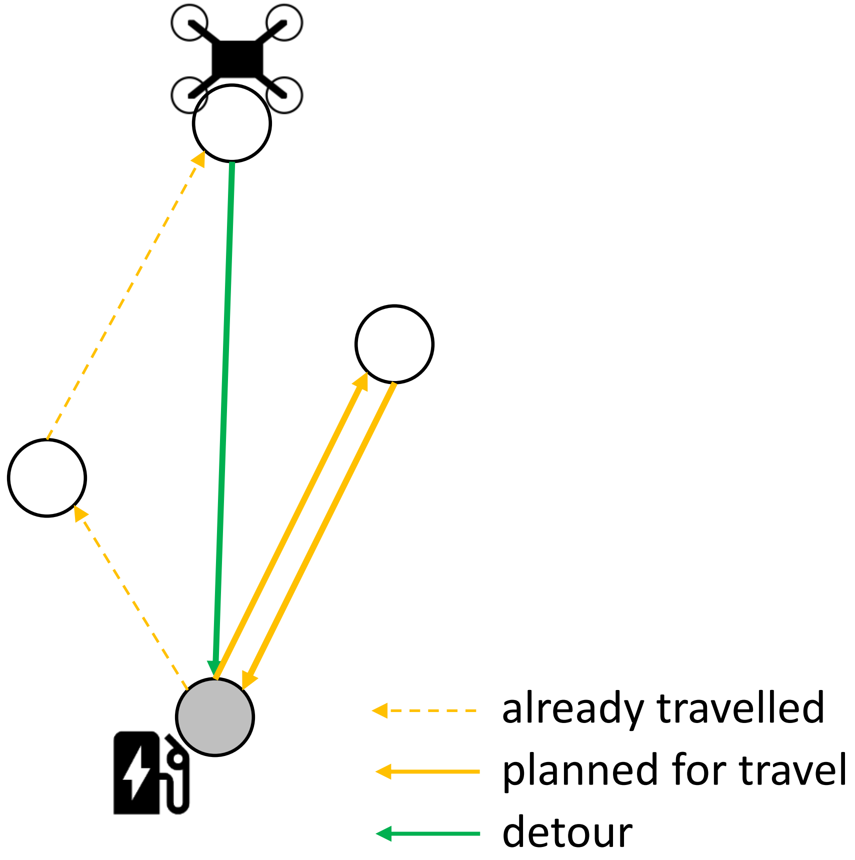


Results: detours

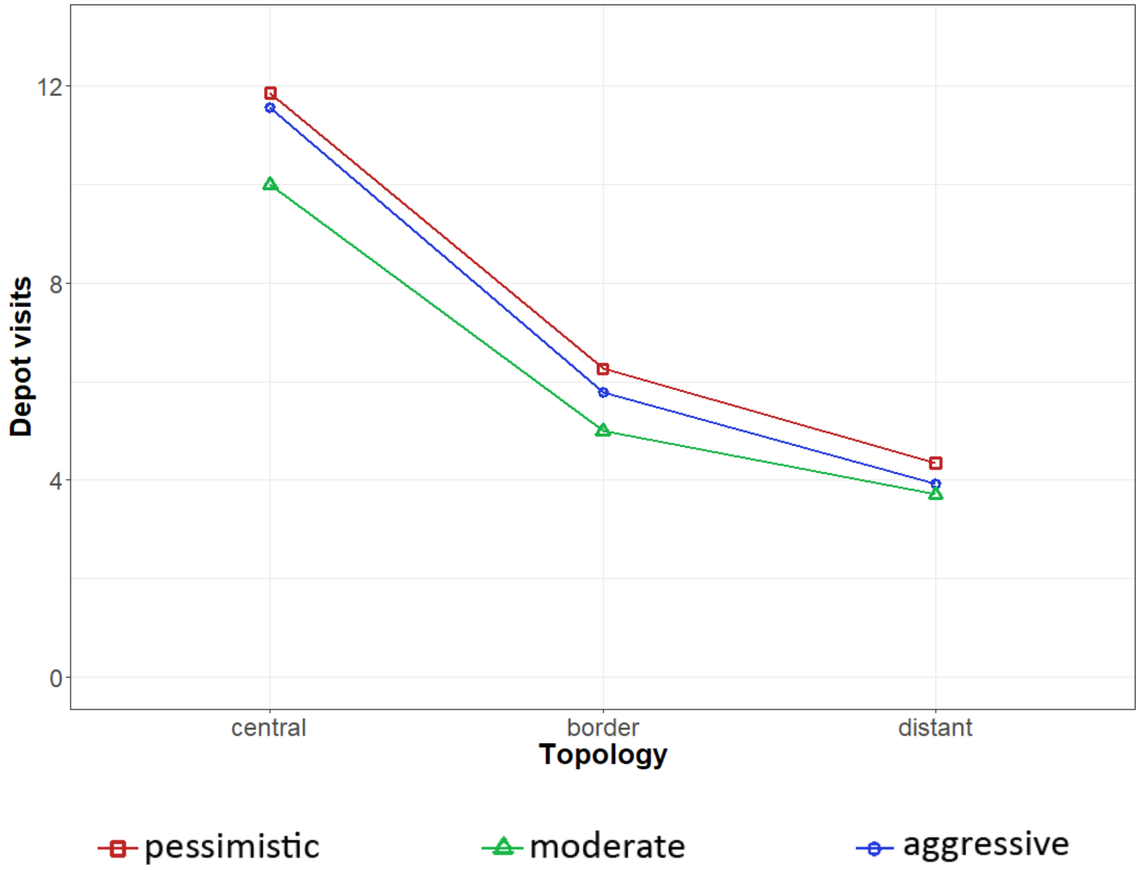


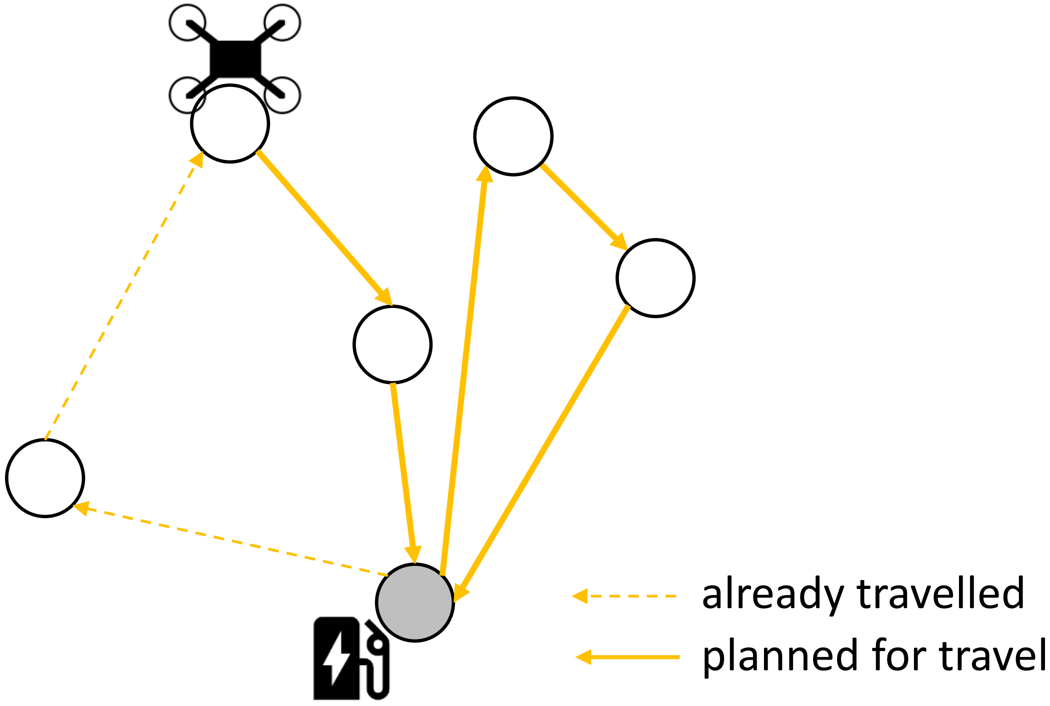
Results: detours



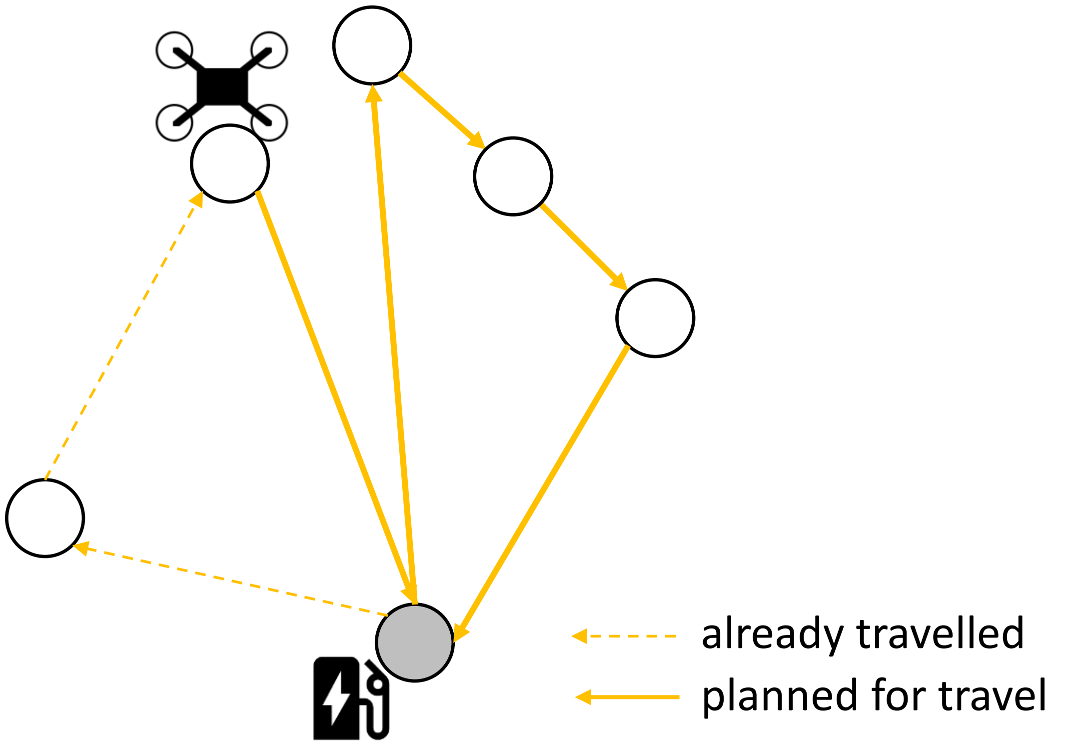


Results: Intermediate depot visits

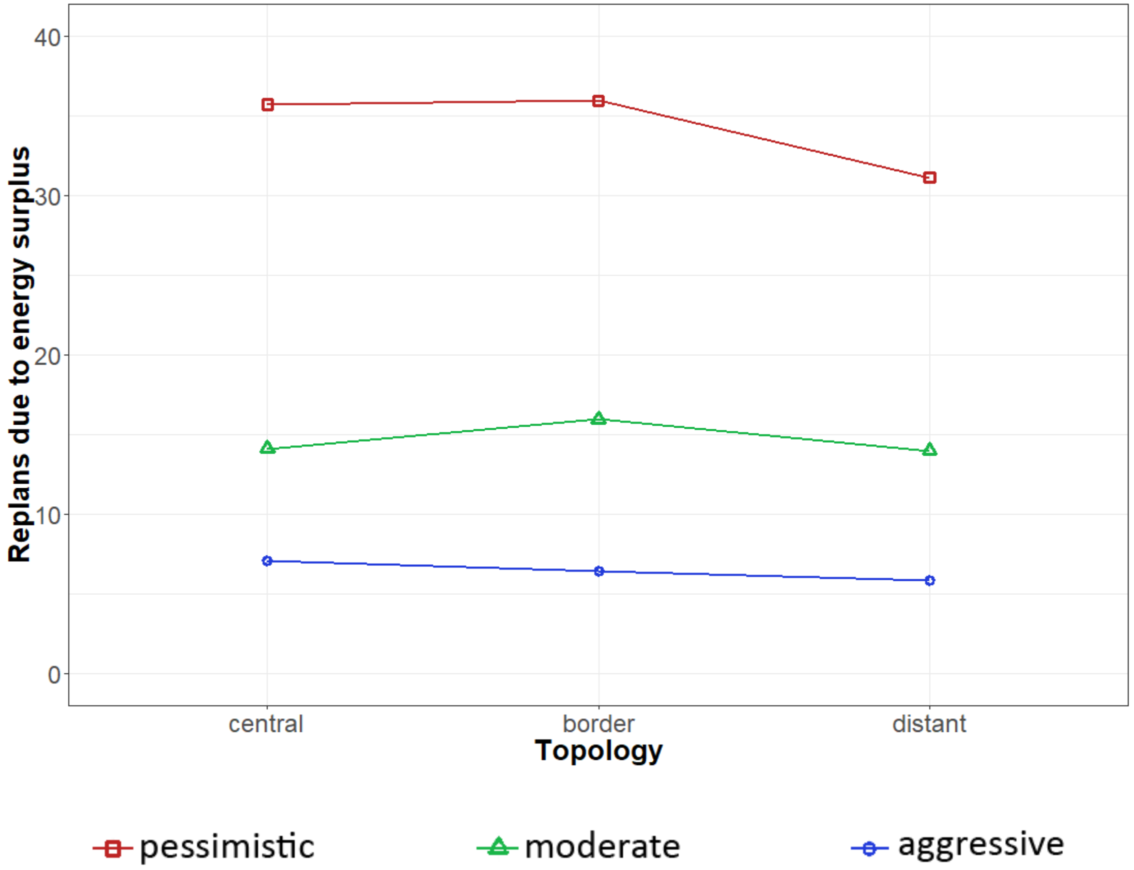


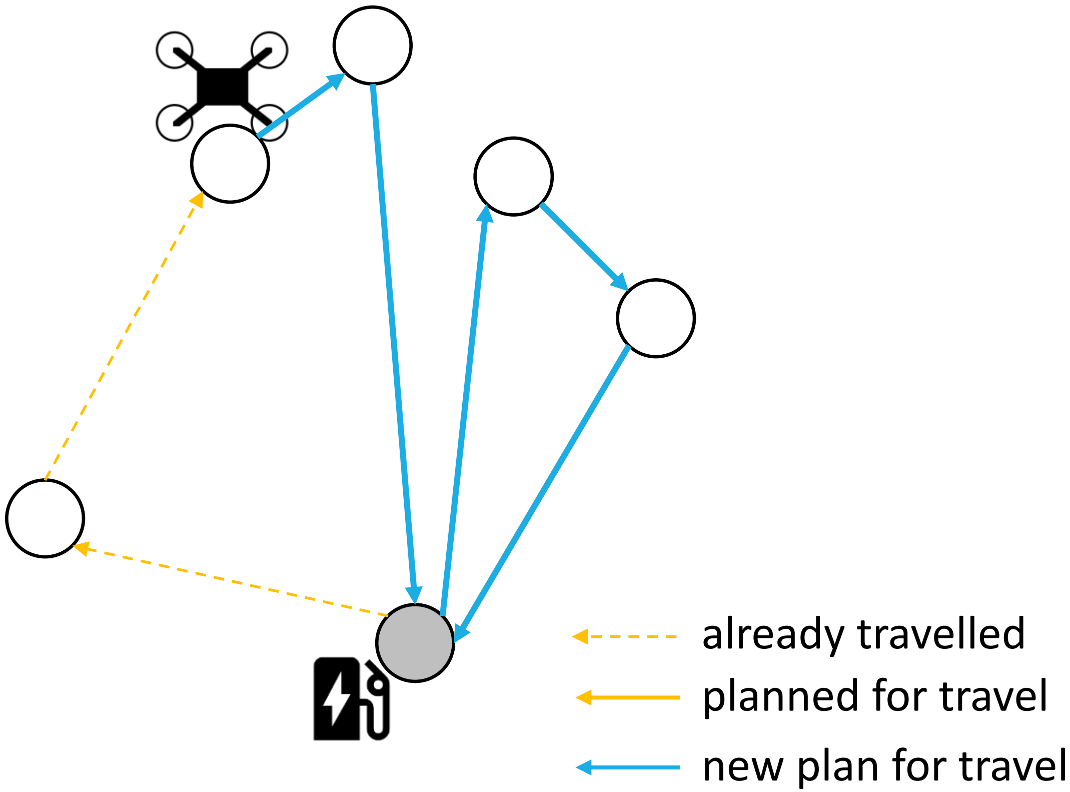


Results: replans



Results: replans





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Conclusion

- Online algorithm
  - Optimistic cost estimations
  - No risk for energy exhaustion
  - Significant makespan reduction vs pessimistic online algorithm
  - Results close to the oracle

- Future work
  - Explore adaptive cost estimation policies
  - Experiment with different uncertainty distributions
    - between different regions and/or over time

Acknowledgements

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Co-financed by Greece and the European Union

Thanks for watching!

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https://csl.e-ce.uth.gr/projects/pv-auto-scout

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