Energy-Efficient UAV Flight Planning for a General PoI-Visiting Problem with a Practical Energy Model

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Outline

- Background
- Problem Modeling
- Solution
- Simulation
- Conclusion

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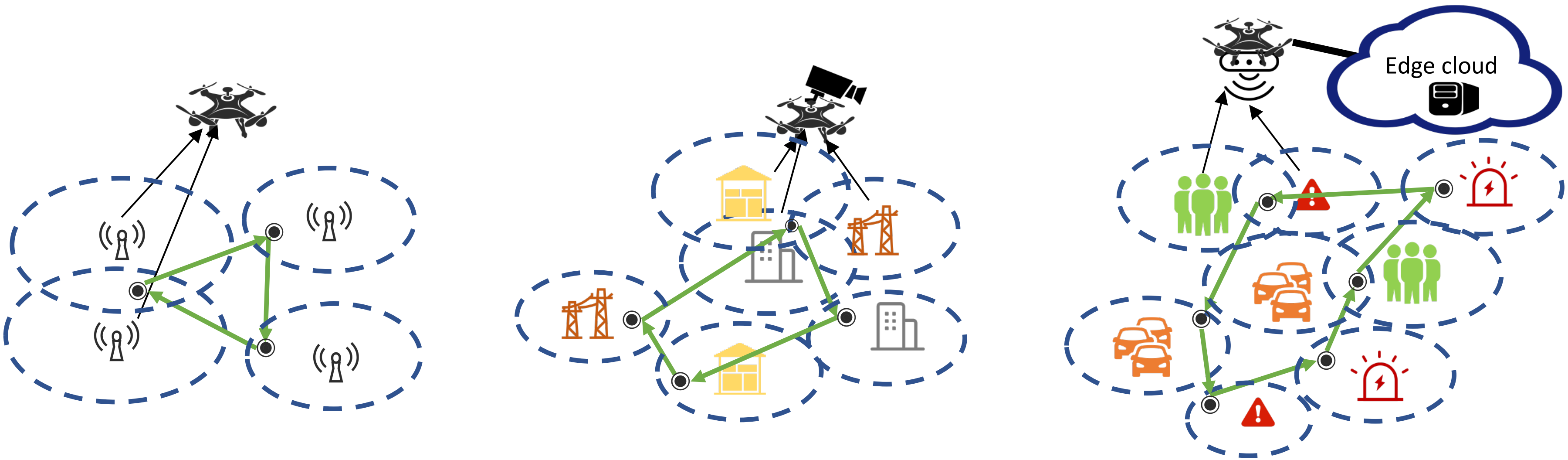
UAV application scenarios



Data collection

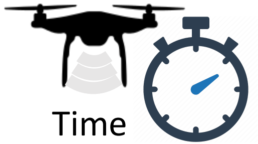
Surveillance & Monitor

Edge computing

Energy consumption problem of UAVs

- Limited energy supply on board
- Flight power 1000 times communication power
- Related flight energy consumption models

distance-related energy model

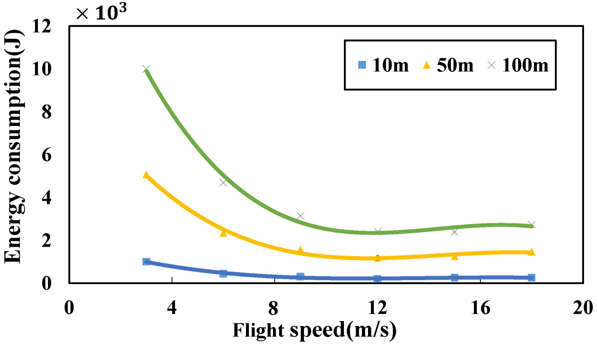


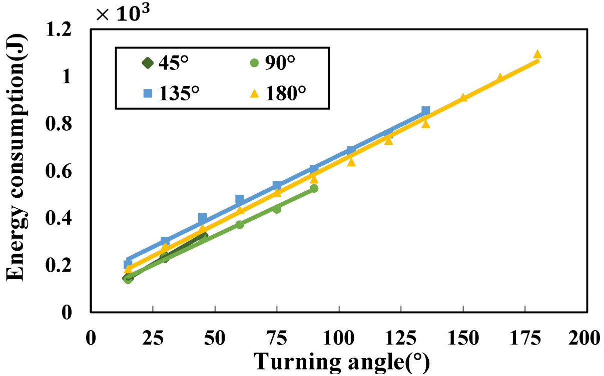
duration-related energy model

Too simple to be accurate

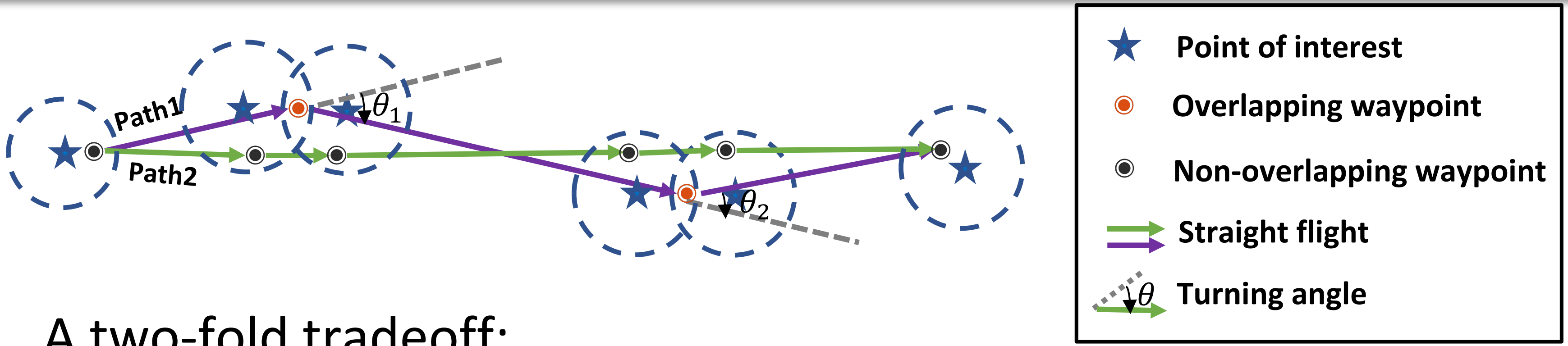
Our practical flight energy model

Our flight tests





Challenges to our problem



A two-fold tradeoff:

- waypoints and straight flight distance
- waypoints and turning angle and the number of switching

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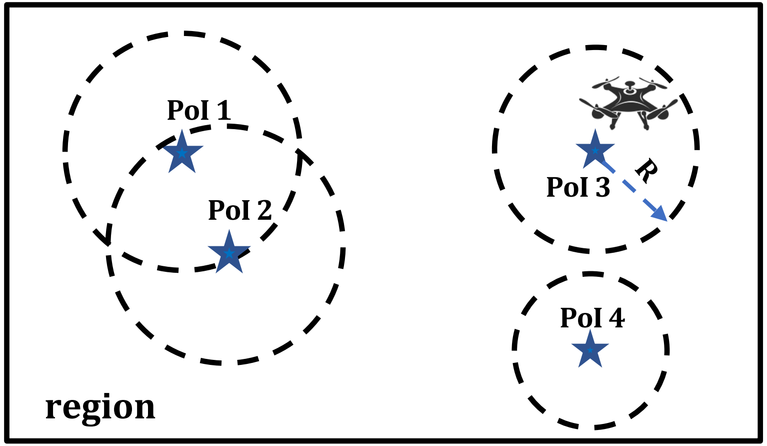
System model

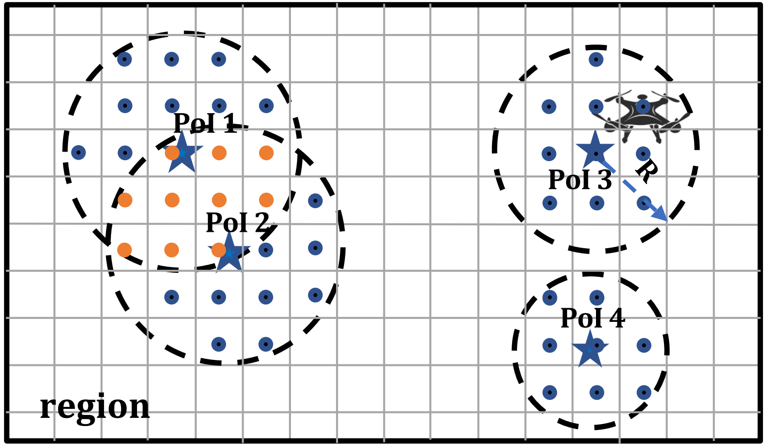
- N PoIs are randomly located in a rectangle region.
- Each PoI has a circle range.
- The UAV files at a fixed height.



Original system model

System model

- Rasterize the region at a certain granularity.
- Take grid centers that fall within each PoI range as its candidate waypoints.
- Waypoints may overlap.



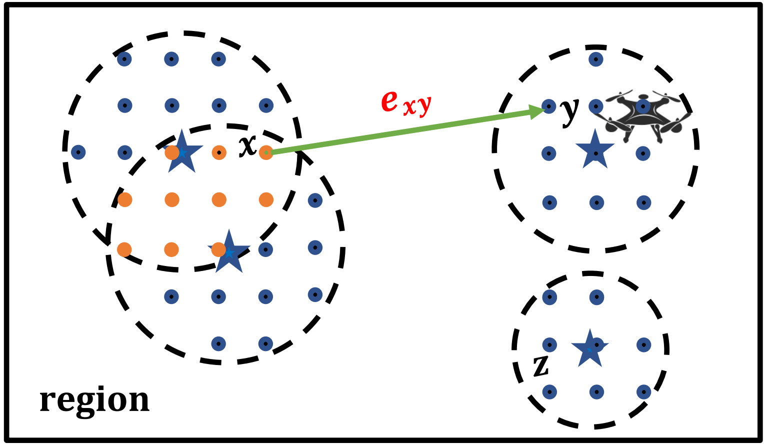
Rasterize region

Energy consumption model

- Straight flight energy consumption:

$$E(e_{xy}) = c_1|e_{xy}| + C_1$$

$$E_C = \sum_{\forall x, \forall y} E(e_{xy}) w_{xy}$$

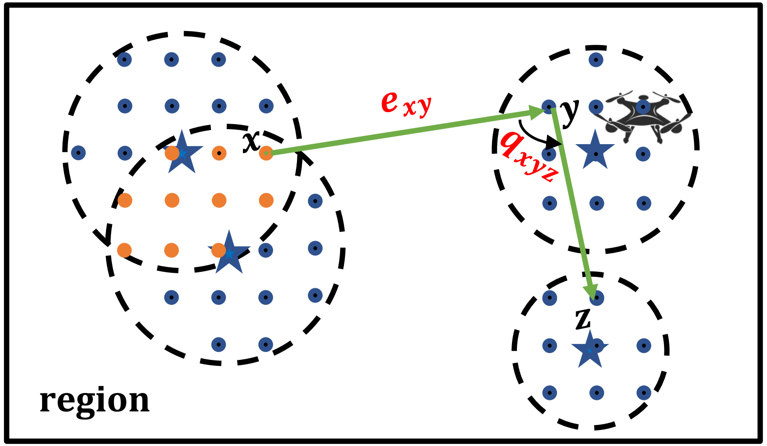


Energy consumption model

- Turning energy consumption:

$$E(q_{xyz}) = c_2 q_{xyz} + C_2$$

$$E_T = \sum_{\forall x, \forall y, \forall z} E(q_{xyz}) w_{xy} w_{yz}$$

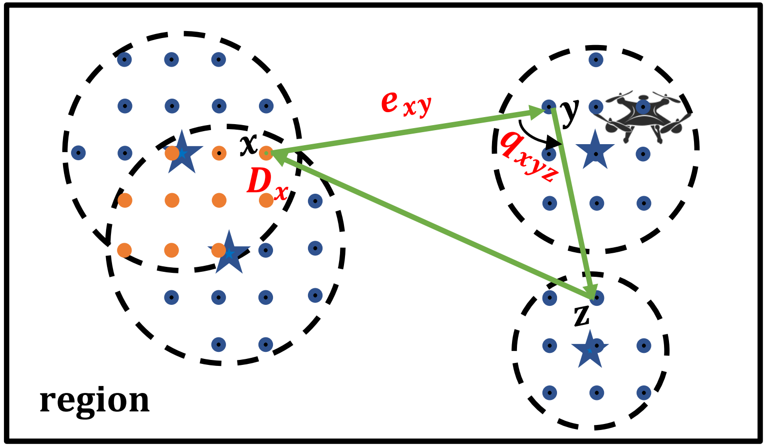


Energy consumption model

- Switching energy consumption:

$$E(D_x) = c_3(|D_x| - 1)$$

$$E_S = \sum_{\forall x} E(D_x)$$

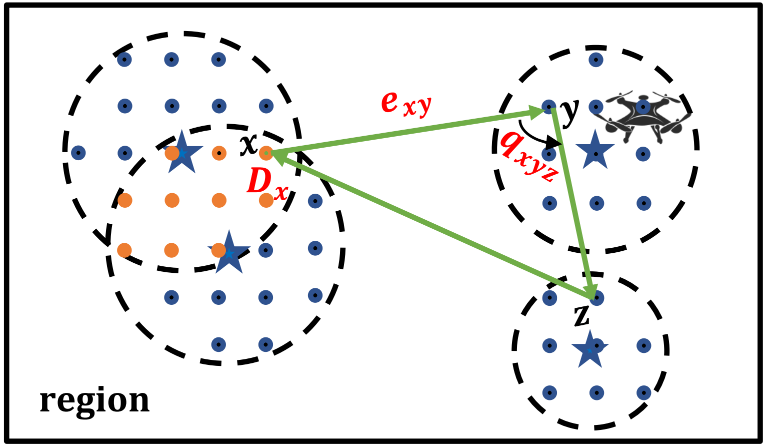


Energy consumption model

- Total UAV energy consumption:

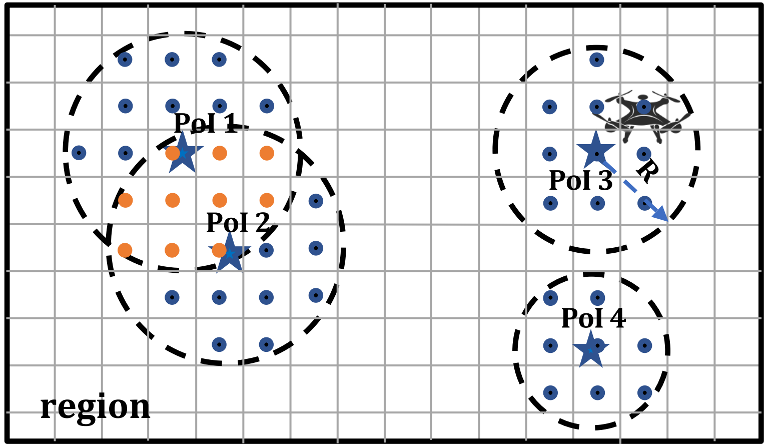
$$\boldsymbol{E_{ALL}} = E_C + E_T + E_S$$

$$= \sum_{\forall x, \forall y} E(e_{xy}) w_{xy} + \sum_{\forall x, \forall y, \forall z} E(q_{xyz}) w_{xy} w_{yz} + \sum_{\forall x} E(D_x)$$



System model

1. Visiting constraint
   - Visit each PoI at least once.
2. Range constraint
   - Visit each PoI within its range.



Waypoint-based PoI-visiting problem

Waypoint-based PoI-visiting problem : find a route to

Δ minimize UAV energy consumption E_{ALL}

- satisfy visiting constraint
- satisfy range constraint

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Problem Transformation

Waypoint-based PoI-visiting problem

?

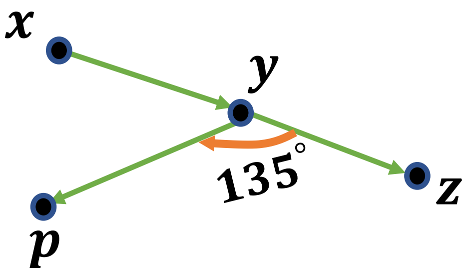
Turning energy consumption

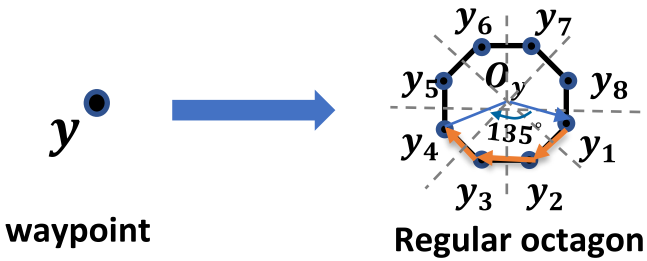
Switching energy consumption

Generalized traveling salesman problem

Modeling energy cost of making turns

- How to embed the energy cost of **making turns** into a graph?



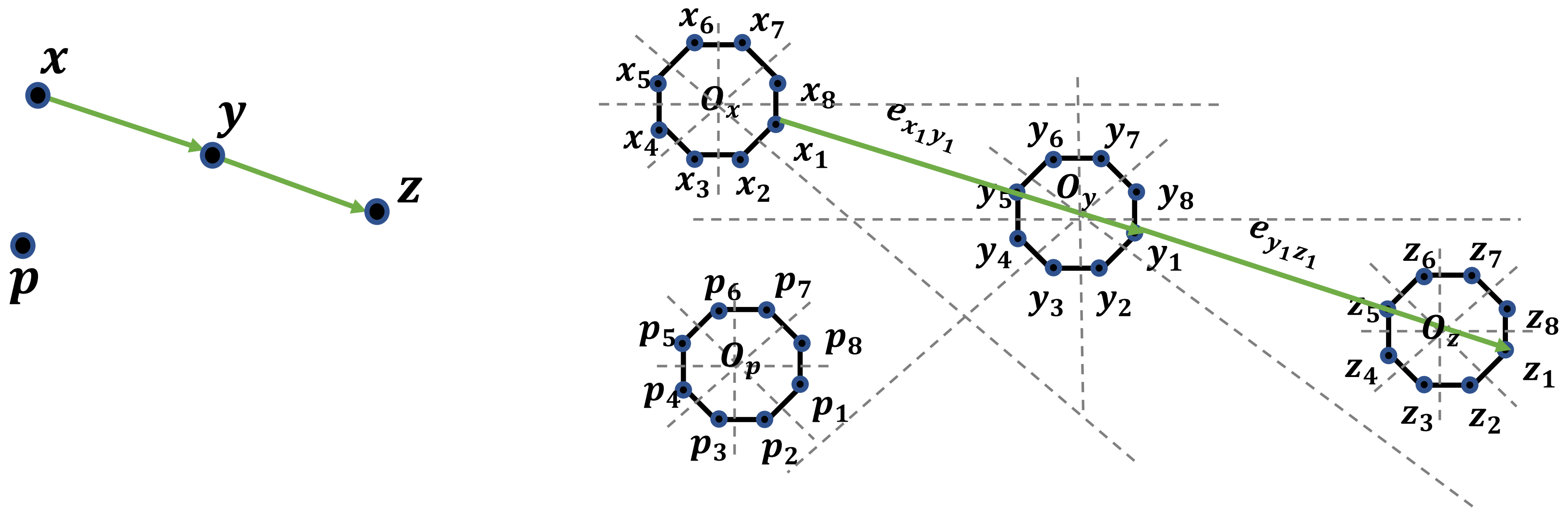


Turning energy cost : $E(q_{xyp}) = E(135°)$

$E(q_{xyp}) = E(e_{y_1y_2}) + E(e_{y_2y_3}) + E(e_{y_3y_4})$

Modeling energy cost of making turns

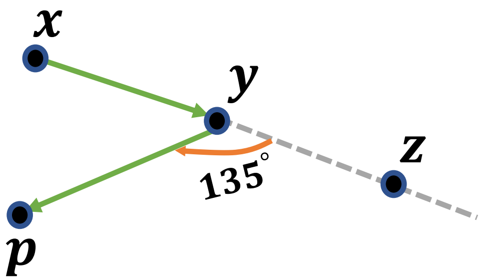
- How to embed the energy cost of **making turns** into a graph?

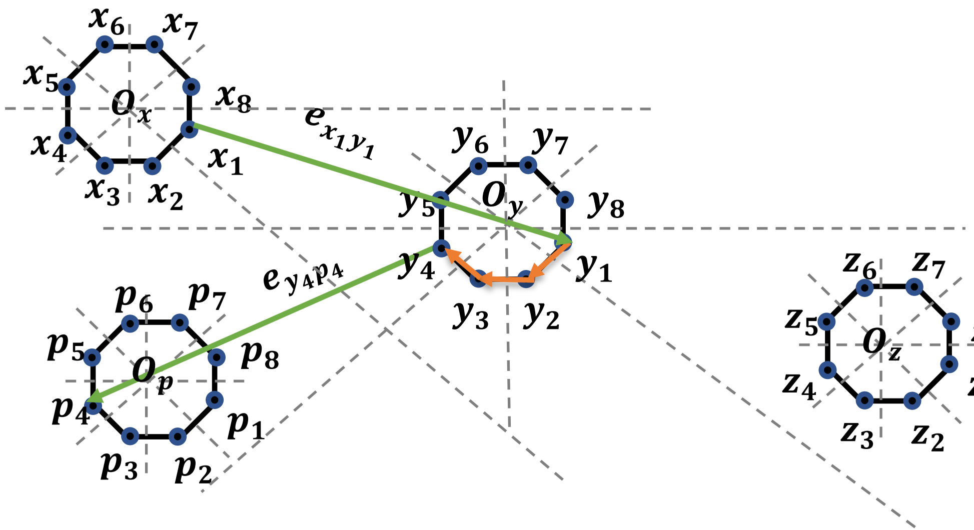


No turning energy cost

Modeling energy cost of making turns

- How to embed the energy cost of **making turns** into a graph?

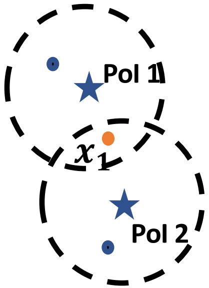


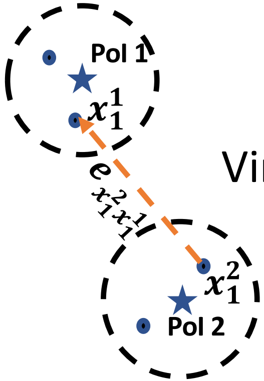


135° turning energy cost

Modeling energy cost of PoI-switching

- How to embed the energy cost of **PoI-switching** into a graph?





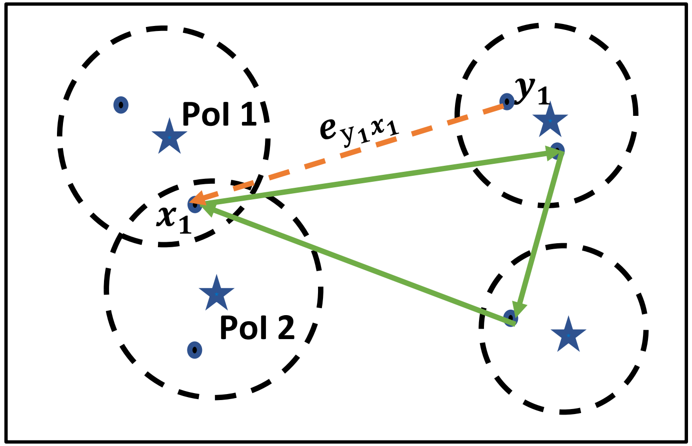
Virtual vertices: x_1^1, x_1^2

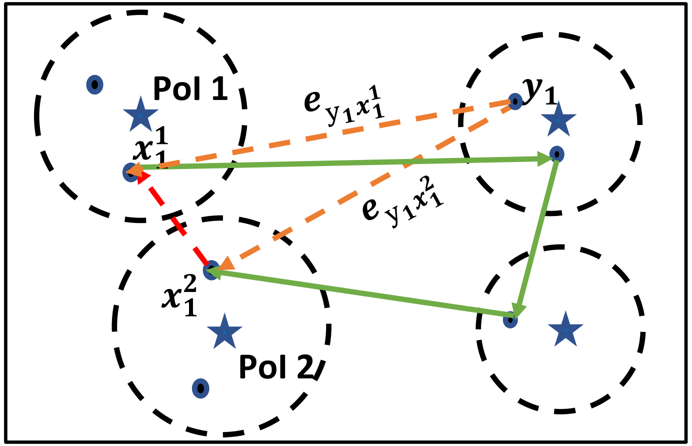
Switching energy cost : $E\left(D_{x_1}\right) = E(1)$

$E\left(D_{x_1}\right) = E(e_{x_1^2 x_1^1})$

Modeling energy cost of PoI-switching

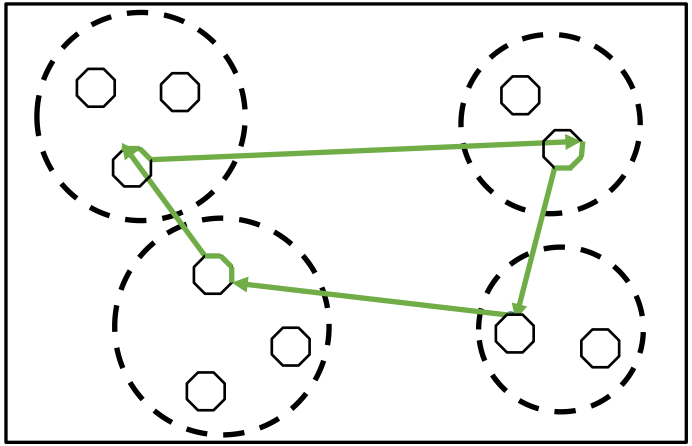
- How to embed the energy cost of **PoI-switching** into a graph?





Redefinition of the problem

- Given a directed weighted graph D = (S,E,W), to find a cycle to visit each subset at least once with the minimum sum of weights of all visiting-edges.



Redefinition of the problem

- Objective function:

$$Min \sum_{v_i, v_j \in S, <v_i, v_j> \in E} c_{ij} w_{ij}$$

- Constraints:

1. Subset coverage
2. Tour continuity
3. Subloop avoidance

Waypoint-based PoI-visiting problem

redefinite

Generalized traveling salesman problem

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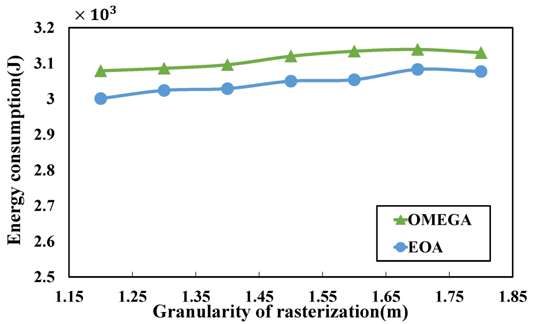
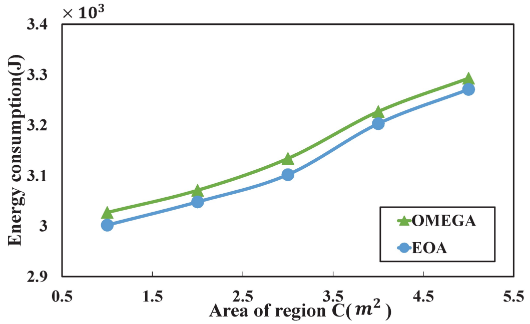
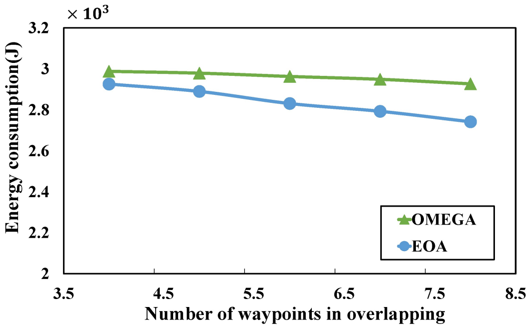
Simulation

- Small scale problem



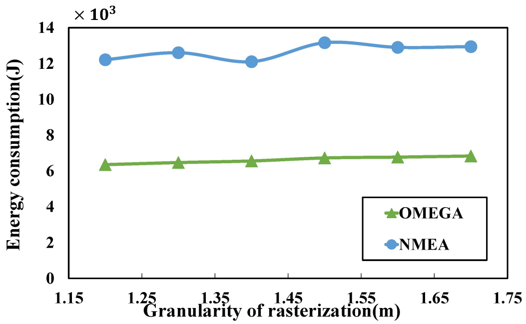


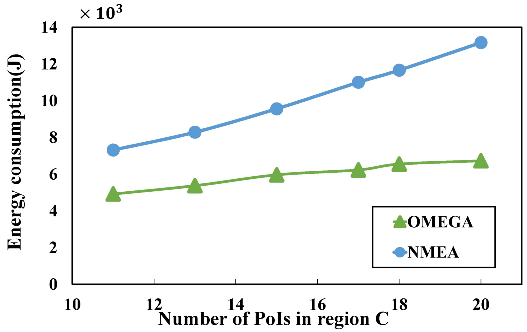


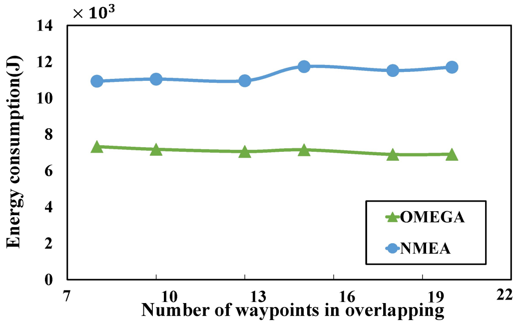
OMEGA spends < 107% of the energy of EOA.

Simulation

- Large scale problem







OMEGA saves ~50% more energy than NMEA.

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Conclusion

1. Real-world flight tests: a more practical energy model.
2. Investigate the general waypoint-based PoI-visiting problem to find a tour with the minimum UAV energy cost.
3. Propose a graph-based algorithm to transfer the problem into a classic graph problem.
4. Conduct simulations to evaluate the performance of our proposed algorithm.

Thank You!

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