Noise-Aware Power Management and Path Planning of Hybrid UAVs

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Contents

Hybrid Fuel UAVs

Multiple fuel sources can extend flight range

Batteries, Hydrogen FCs, Solar, Combustion Engine

Fuel sources each have strengths and weaknesses

Combustion engines are loud/heavy but have high energy density

Batteries have high power density, low (relative) energy density

Problem Motivation

We are motivated by two scenarios

- Widespread use of UAVs in urban environments
  - Increase in frequency and intensity of ground-level noise in future
  - Noise restrictions put in urban / residential areas in response
  - Thus, need planning for UAVs in presence of noise restrictions
- Noise-sensitive surveillance missions in military context
  - Certain air spaces may have restrictions on noise produced by agents

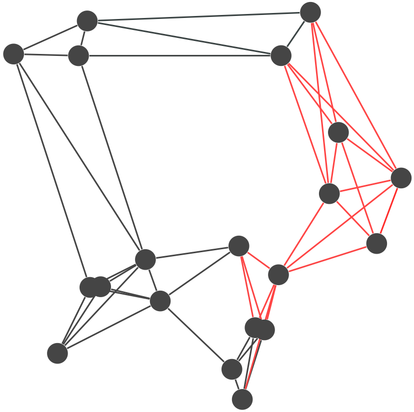
Hybrid UAV Routing Problem

Problem is to plan for a hybrid-fuel UAV in presence of noise restrictions

Problem is to find the shortest path to the goal which satisfies:

- Noise Restrictions
- Fuel constraints

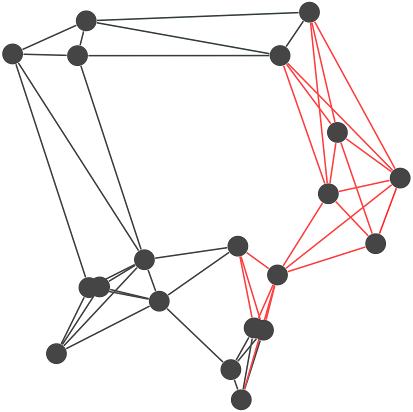
Path and power management problems are coupled, and must be solved in tandem.



Initial approach in discrete framework. Reminiscent of well-known problems: SPPTW, RCSPP, network optimization

Dynamic Programming Algorithm

- We formulate a label-setting algorithm in a Dynamic Programming framework to solve the MILP exactly
- Keep track of a set of labels for each node corresponding to partial paths
- Iteratively expand labels to neighboring nodes and discarding inefficient labels



Dynamic Programming Algorithm

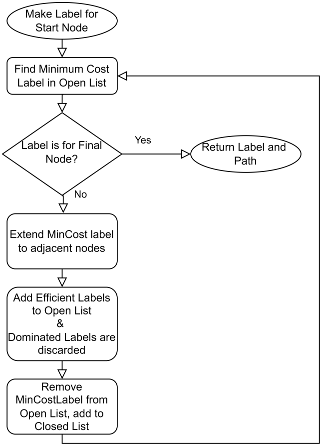
Standard SPP: a single value assigned to nodes - cost-to-arrive

In presence of resources, this cannot be used

Each node has a *set of labels*

- label describes a *path to a node* by the cost to arrive and resource consumption

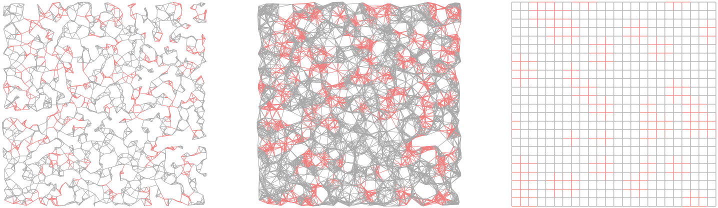
Labels cannot dominate others simply by cost



Labeling Algorithm

Pseudo-polynomial running time with integer edge parameters
Scaling of labeling algorithm was evaluated numerically

- Large set of graphs of varying size, construction, and connectivity
- Implemented in Julia language v1.9



Results

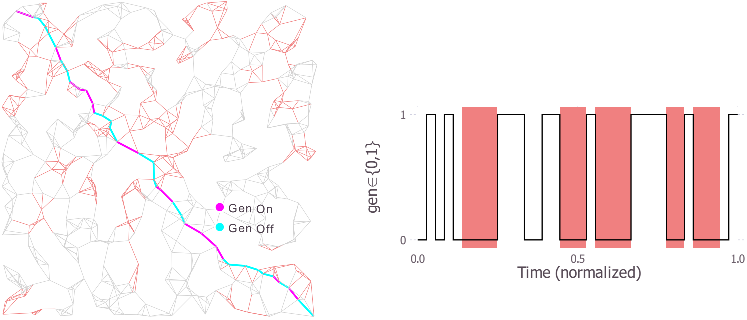


Figure 2: Example Solution - 550 Nodes

Results

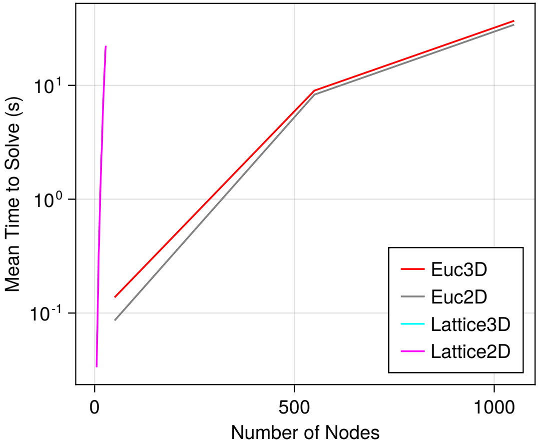
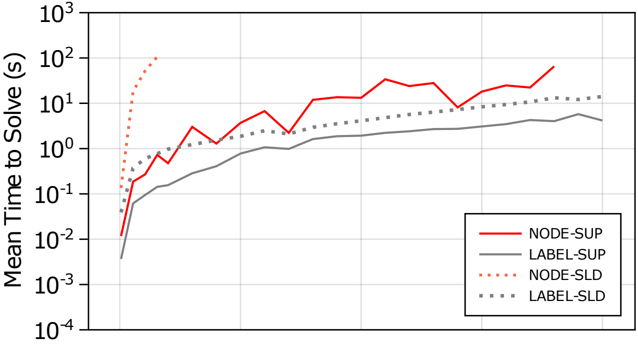


Figure 3: CPLEX Branch and Bound Results

Branch-and-Bound scales poorly

Feasible for very small graphs relative to labeling algorithm.

Results



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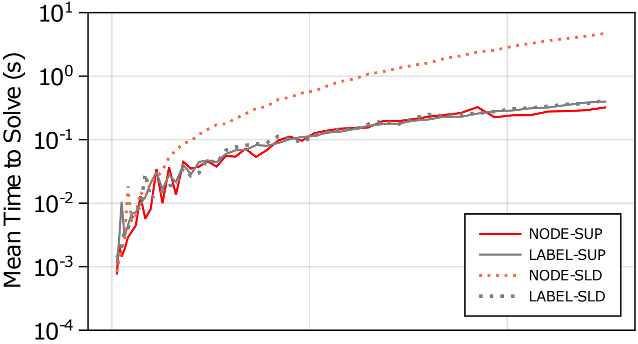
Labeling algorithm tested on Lattice (grid) graphs

Two different selection methods

Two different cost-to-go estimations (A^* and euclidean distance)

Results



Labeling algorithm tested on random-node-placement graphs - nearest-neighbors connection

Two different selection methods

Two different cost-to-go estimations (A^* and euclidean distance)

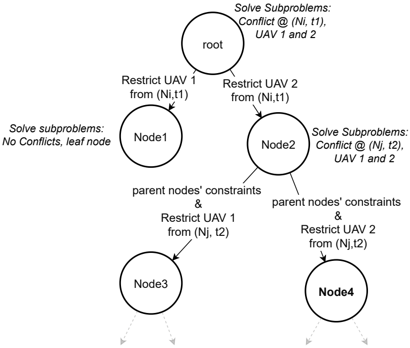
Multi Agent Path Finding

Fast, scalable algorithm for single-agent planning
Extension to multi-agent planning
Multi-Agent Pathfinding
- Well studied NP-hard problem
- Relevant to UAV Traffic Management
We extend the MAPF to consider our hybrid-fuel and noise restrictions

Multi Agent Path Finding

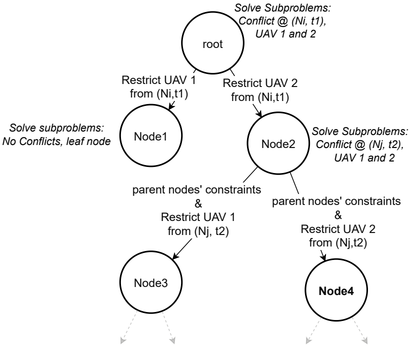
Conflict Based Search - recent (2015) approach to solving MAPF
Similar to cutting-plane algorithms
Collision constraints relaxed

- Iteratively add individual constraints
- Branching to add constraints to one UAV for each collision



Multi Agent Path Finding

At each node, solve set of shortest path problems
- Subject to set of collision constraints at that node
- Hybrid-fuel, noise restrictions: use our labeling algorithm to quickly solve



MAPF Testing Results

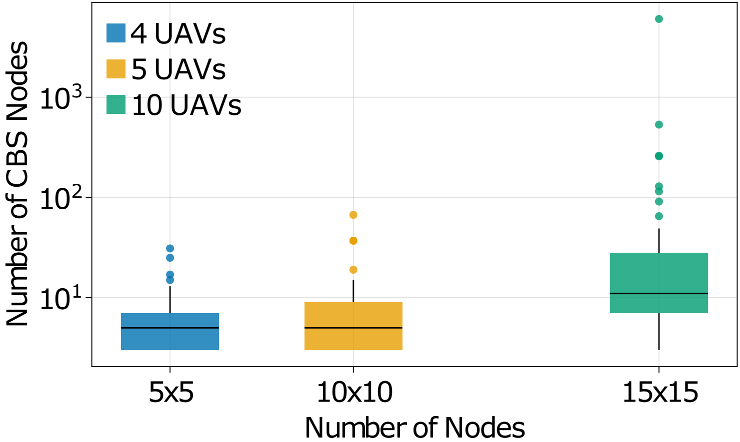


Figure 4: CBS Nodes Searched vs Problem Size

MAPF Testing Results

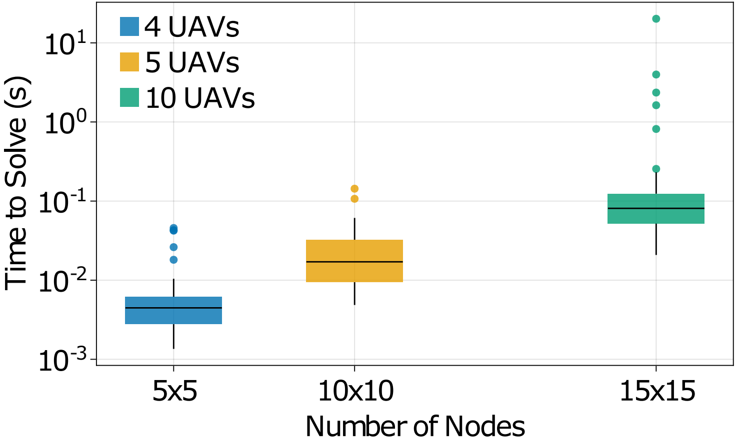
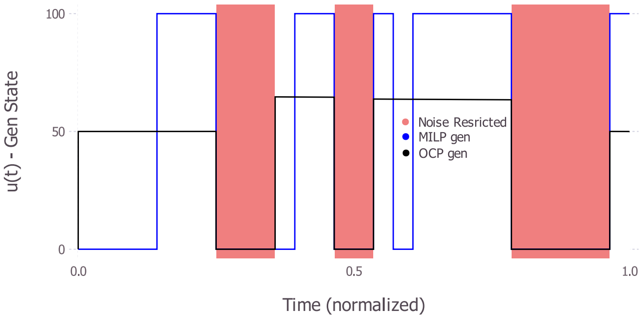


Figure 5: Time to Solve (s) vs Problem Size

Optimal Control

Discrete approach scales well
Quality of path is subject to graph construction
Generator pattern quality is low
- Considers only on/off states in search
Frequent switching, full throttle is lower efficiency
Optimal control approach to find optimal generator policy for a given path

Optimal Control



OCP can set generator throttle to any state
Improved fuel consumption over MILP
Scales well with larger paths when solving with even-collocation

Conclusions and Future Work

Labeling algorithm scalable to large problems
Effective to repeatedly solve a subroutine in multi-agent problems
Future Work:

- More extensive numerical testing MAPF
  - Larger problems
  - CBS variants
- Extension of optimal control problem