Expanding the ROS2 Navigation Stack for multi-robot search tasks

ROB 599, Mobile Robotics

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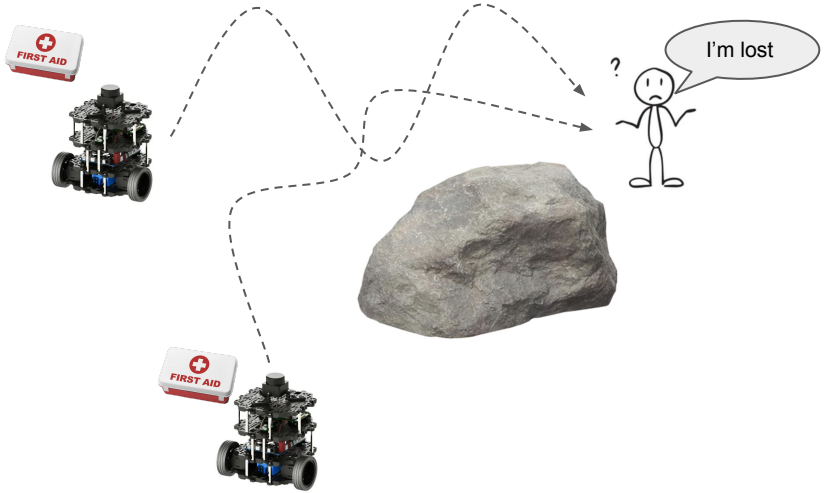
Motivation





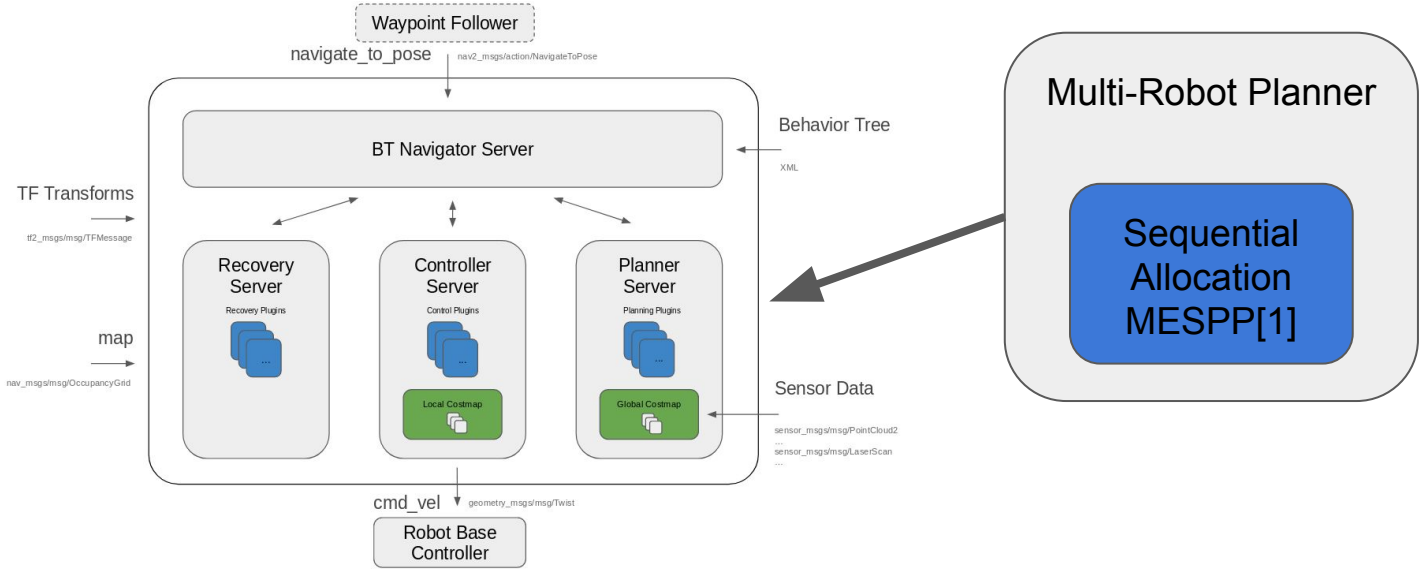
Challenges and Gap

The current ROS2 Navigation Stack is effective at solving the single robot navigation problem. However, in the **multi-robot search domain** [1,2,3] navigation using paths generated without coordination perform poorly.



Solution

We propose combining **ROS2 Nav2 + Multi-Robot Efficient Search Path Planning** . By integrating a new **MESPP**[1] module that allows for coordination between multiple robots through the use of a shared belief state.



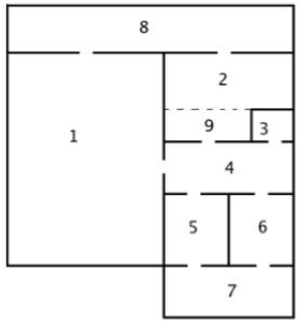
Technical overview

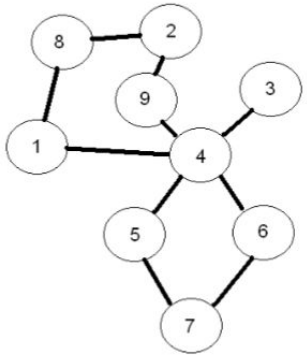
Simulator: Stage

Local planner, motion planning, global planner: ROS2 Nav2

Multi-robot search algorithm:

Sequential Allocation MESPP [1]





Software Integration:

Integrating MESPP with ROS2

Tooling to generate maps, graphs and leverage Nav2

MESSP Algorithm: Problem Setup

Problem formulated as a Mixed-Integer Linear Program (MILP).

MILP Variables:

- integer variables (robot decisions),
- continuous variables (probabilities)

MILP Models:

Target detected if robot is on the same node or within sensing range

Sensors can miss targets with probability

MESSP Algorithm: Robots Motion Model

Target: Target moves according to a probabilistic Markov model

$$M_{uv} = P(\text{target moves from u to v})$$

Searchers: Searchers maintain a belief distribution over possible target locations

$$b(t)=[b_c(t), b_1(t),...,b_n(t)]$$

Belief is updated using: robot sensing and estimated target motion model.

MESSP Algorithm: Optimization Objective

Chose robot paths such that:

$$\pi^* = \arg max_{\pi \in P} \sum_{t=0}^{\tau} \gamma^t b_c(t)$$

Where π is each robot path, y is a discount factor [0, 1]

MESSP Algorithm: Constraints

1. Robots must arrive from neighboring nodes
2. Update target motion using the Markov transition matrix

Algorithm

For each time step t:

    For each robot i = 1 …m

        Fix the paths of other robots

        Solve MILP for robot i

        Update path

    End

    Execute first step of paths

    Update belief

End

Experiments

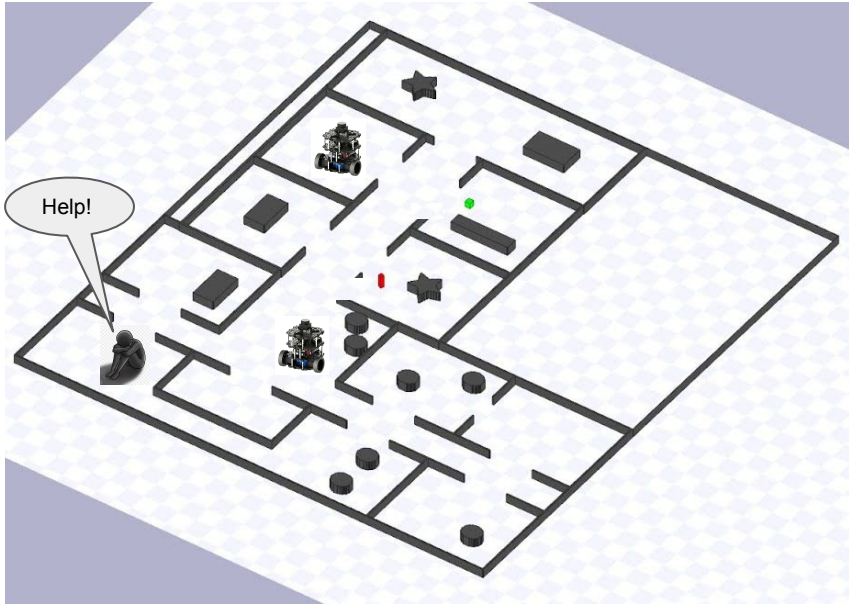
Main Task: Search 1 moving target using 2 robots for capture.

Baseline: Search and planning with naive coordination (exhaustive search)

Ours: Search and planning with coordination through beliefs (MESPP)

The task consists of:

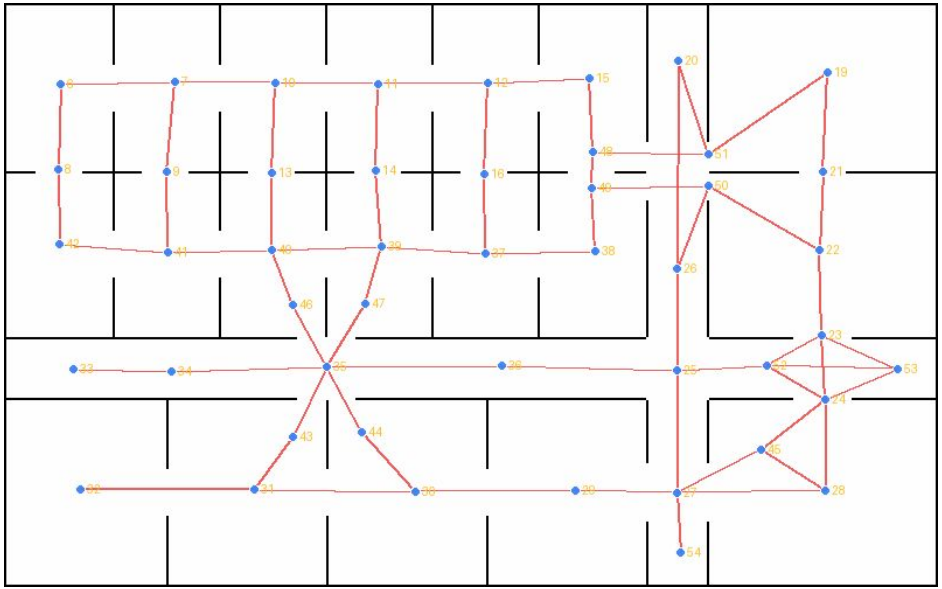
- 2 search robots
- 1 moving target
- 3 worlds
- Capture requires 1 robots



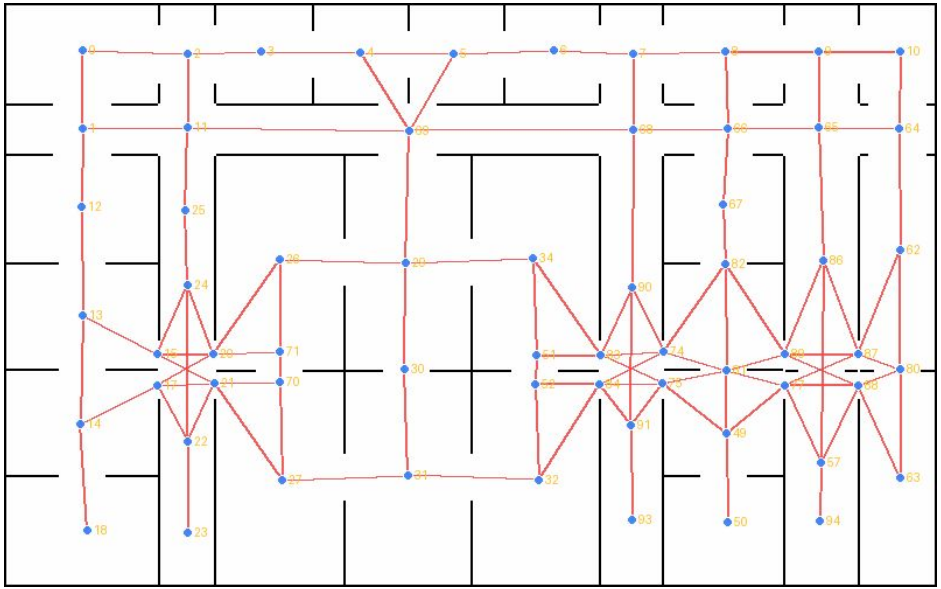
Performance Metric:

Average capture time and node coverage

Worlds and graphs

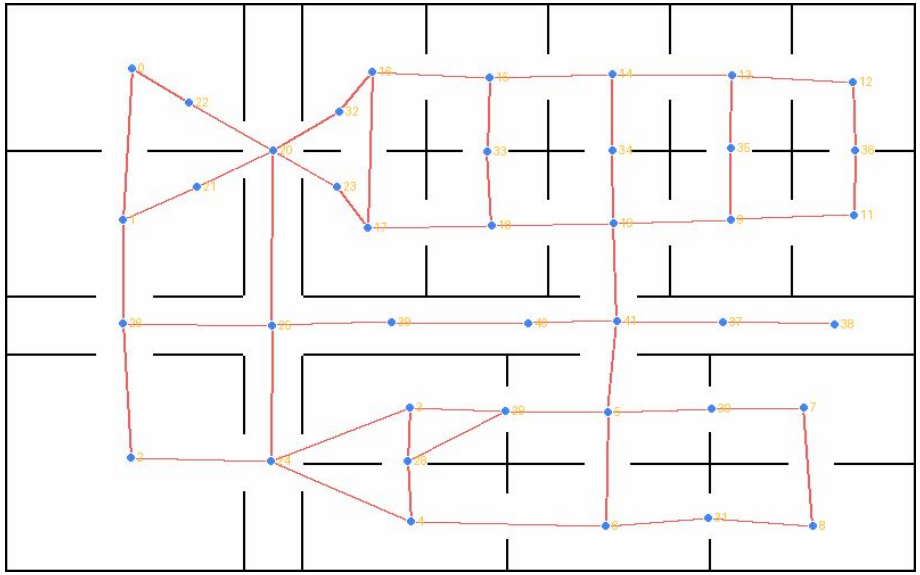


World #1

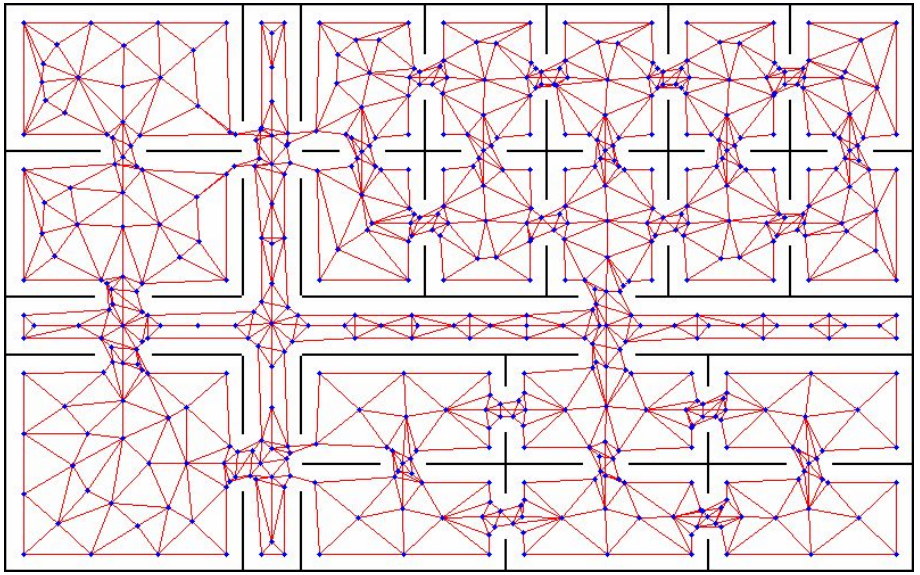


World #2

Worlds and graphs



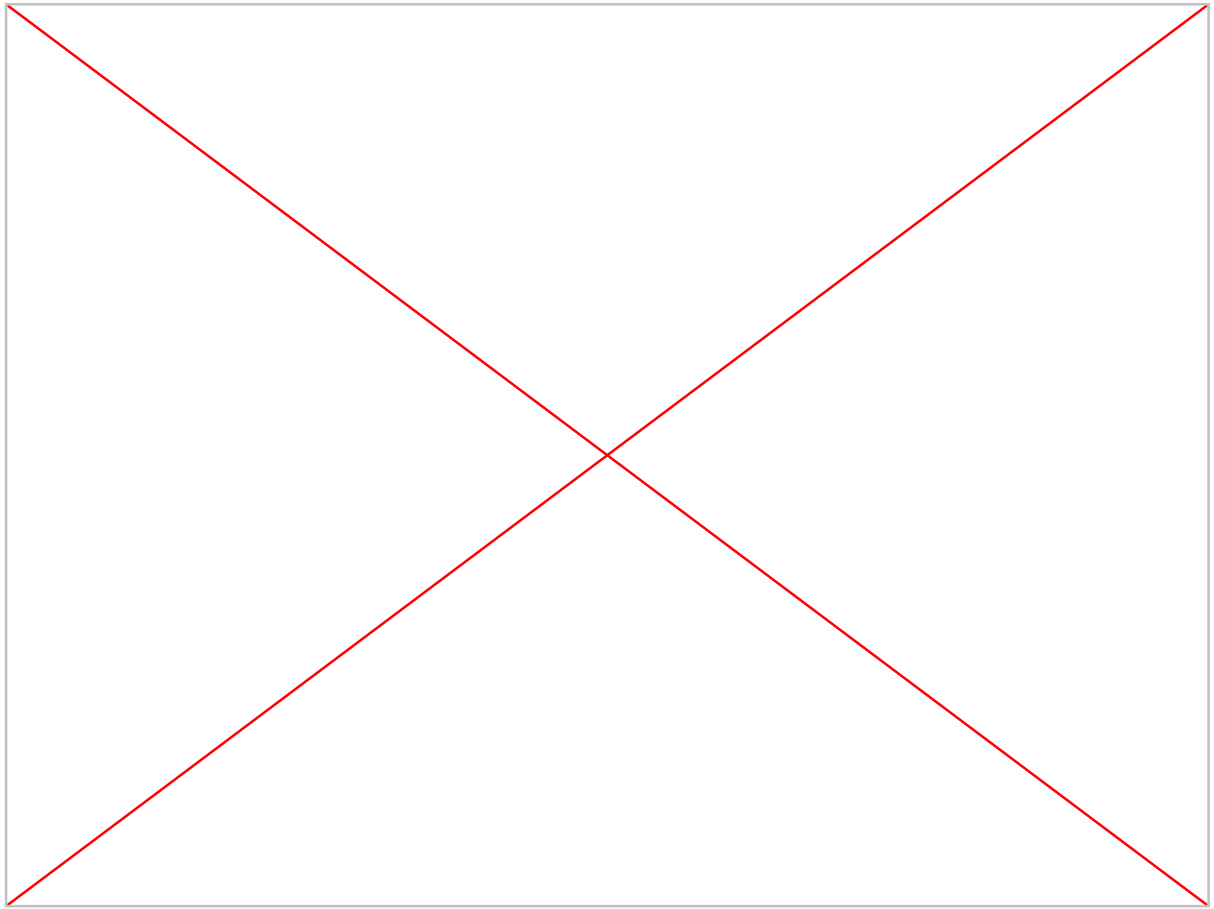
World #3



World #3 (dense)

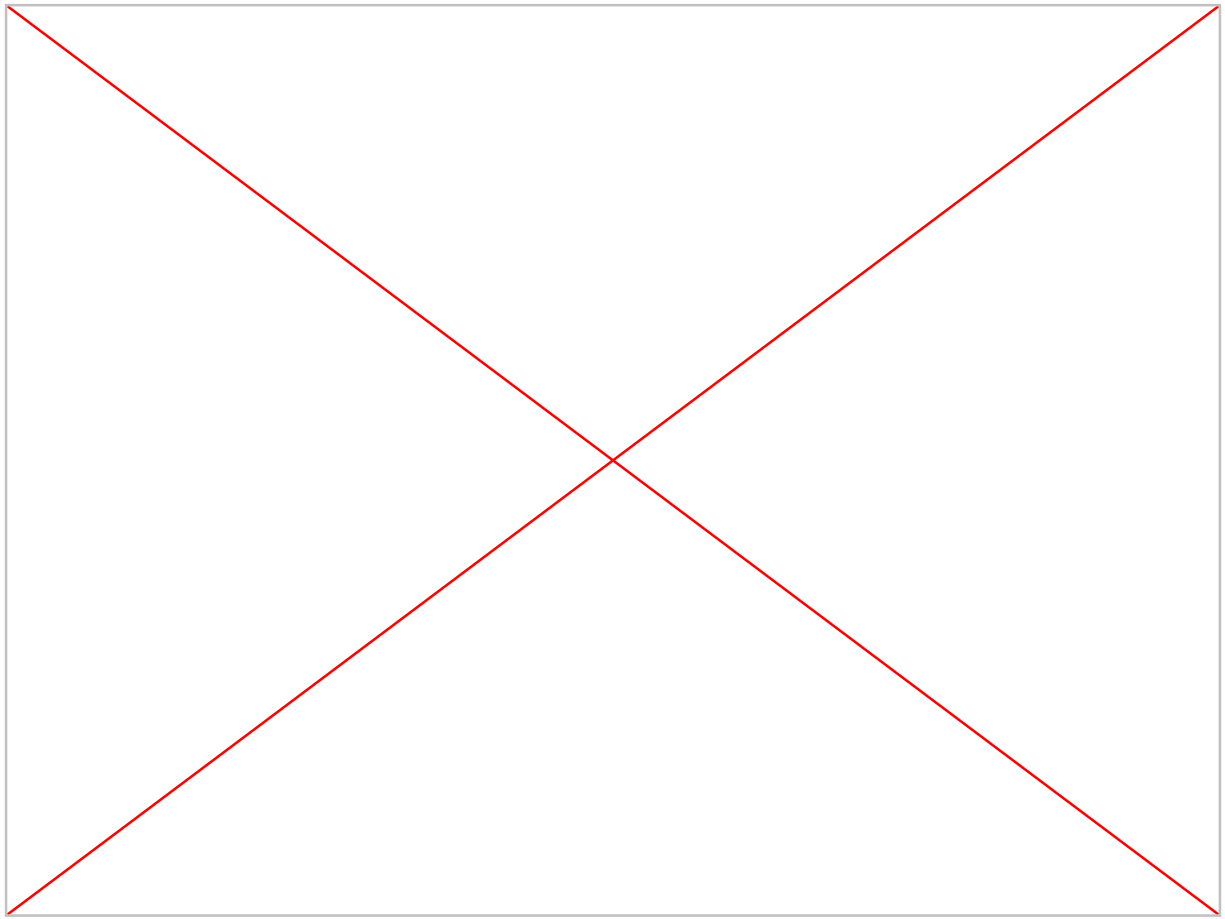
Results: Simulation

World #1



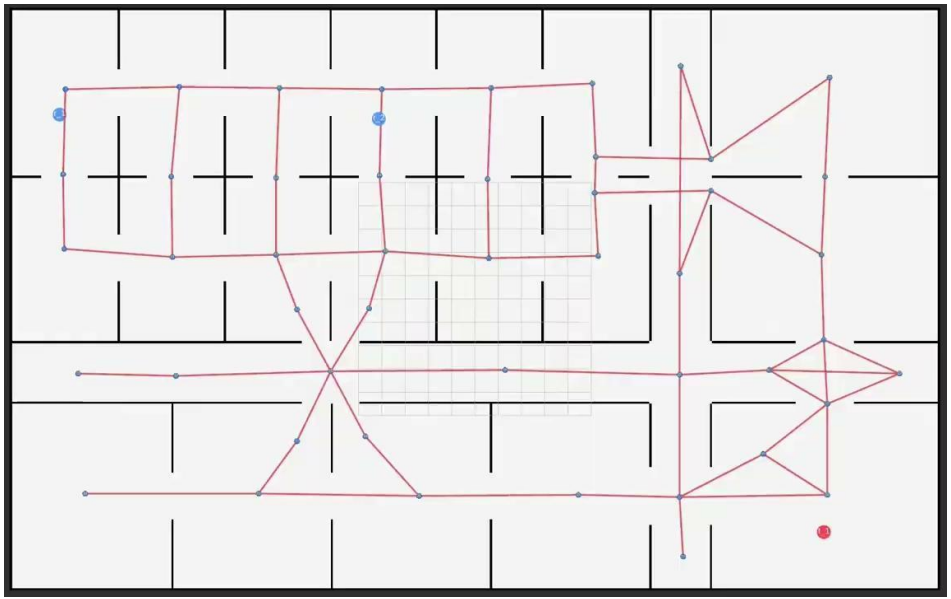
Results: Simulation

World #2

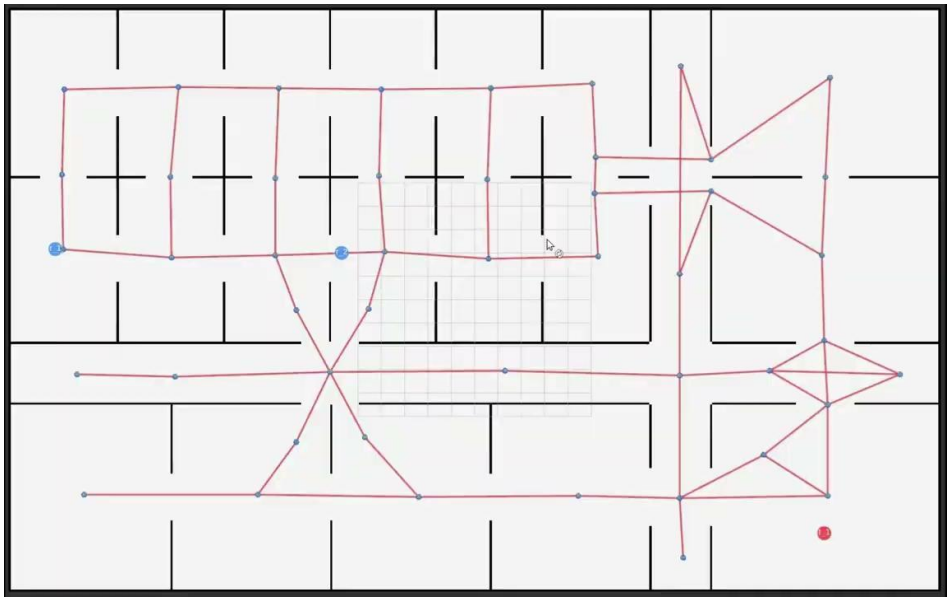


Baseline vs. MESPP

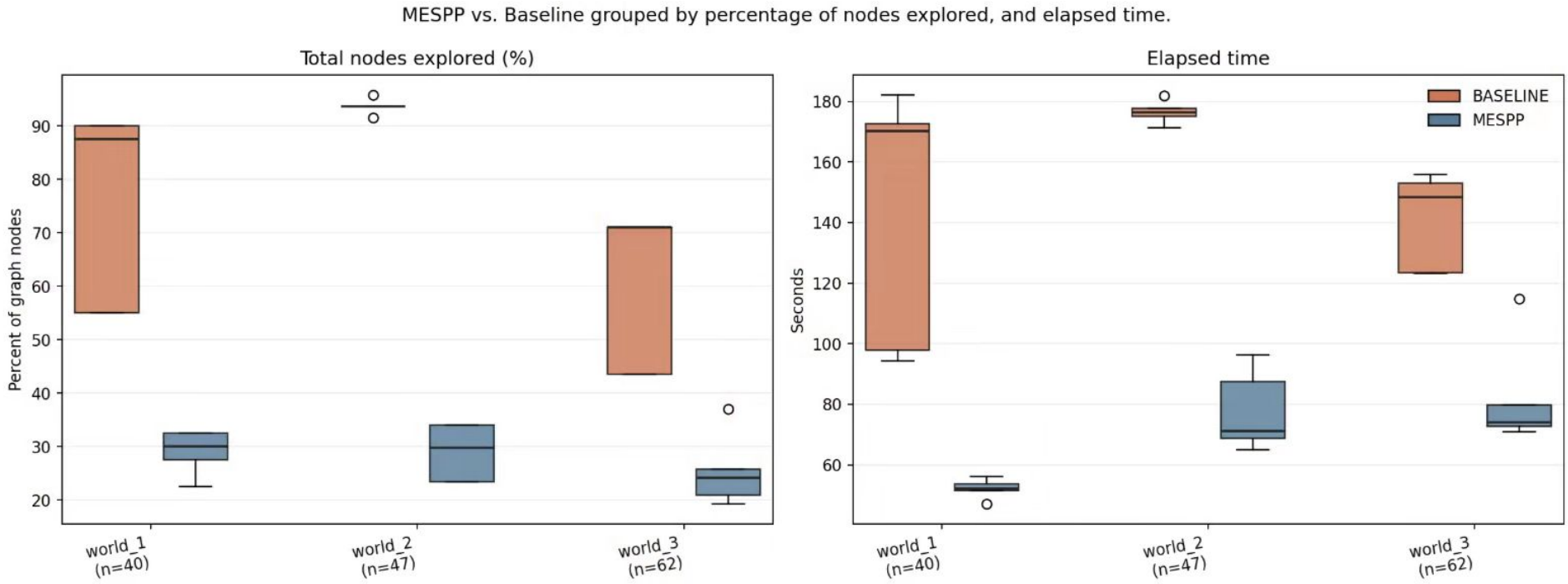
Baseline (Exhaustive search)



MESPP



Performance Metrics



Timeline and Progress

Phases	Week	Goals	Responsible	Score
Phase 1	**3**	**Project Proposal**	**Everyone**	**-**
	4	**Stage task creation with multiple robots and a moving target.**	**Manuel**	**5/5**
	5	**Test the NavStack baseline on each robot, and implement average capture time and area coverage percentage metric logging.**	**Manuel and Michael**	**5/5**
	6	**Implement multi-robot search path planning algorithm as a ROS node.**	**Roger**	**5/5**
Phase 2	**7**	**Integrate our approach with ROS2 NavStack** as a plugin.	**Manuel and Roger**	**4/5**
	8	**Run a total of 6 experiments, 1 on each of the 3 environments for baseline and ours.**	**Michael**	**5/5**
	9	**Project presentation.**	**Everyone**	**5**
	10	**Write and submit report.**	**Everyone**	**-**
Stretch Goals		**Run experiments using 3 and 4 robots, with 1 moving target. And 2,3 and 4 robots with 2 moving targets**	**Everyone**	**10**

Discussion and Learnings

- Working with Nav2 is challenging (integration with behavior tree).
- Nav2 is neat when it works.
- The value of the belief state in search.
- Catching a faster or adversarial target is a bigger challenge.

Future work

- Turning our MESPP implementation into a plugin, making it part of the behavior tree.
- Testing on larger maps, with more agents.
- Capturing an adversarial target.
- Introduce more world variety

References

1.- Hollinger, G., Singh, S., Djugash, J., & Kehagias, A. (2009). Efficient multi-robot search for a moving target. *The International Journal of Robotics Research, 28*(2), 201–219.

2.- Kalra, N. (2006). A Market-Based Framework for Tightly-Coupled Planned Coordination in Multirobot Teams. PhD thesis, Carnegie Mellon University.

3.-A. Macwan, J. Vilela, G. Nejat and B. Benhabib, "A Multirobot Path-Planning Strategy for Autonomous Wilderness Search and Rescue," in *IEEE Transactions on Cybernetics*, vol. 45, no. 9, pp. 1784-1797, Sept. 2015, doi: 10.1109/TCYB.2014.2360368. keywords: {Robot kinematics;Robot sensing systems;Probabilistic logic;Probability density function;Optimization;Interpolation;Multirobot coordination (MRC);path-planning;wilderness search and rescue (WiSAR);Multirobot coordination (MRC);path-planning;wilderness search and rescue (WiSAR)},