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Addressing Uncertainty in Decentralised Coordination of Unmanned Aerial Vehicles

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Motivations

Provide live aerial imagery using a team of autonomous UAVs to support first responders at the scene of a disaster.

- First responders request image collection tasks.
- Model the system of tasks and UAVs as a Distributed Constraint Optimisation Problem.
- Goal: Find the optimal task allocation between the team of UAVs.

Utility Function

We define the utility function U_i for each task that encodes the benefit obtained from assigning a particular subset of UAVs to task T_i.

- Priority, p_i
- Urgency, u_i
- Duration, d_i

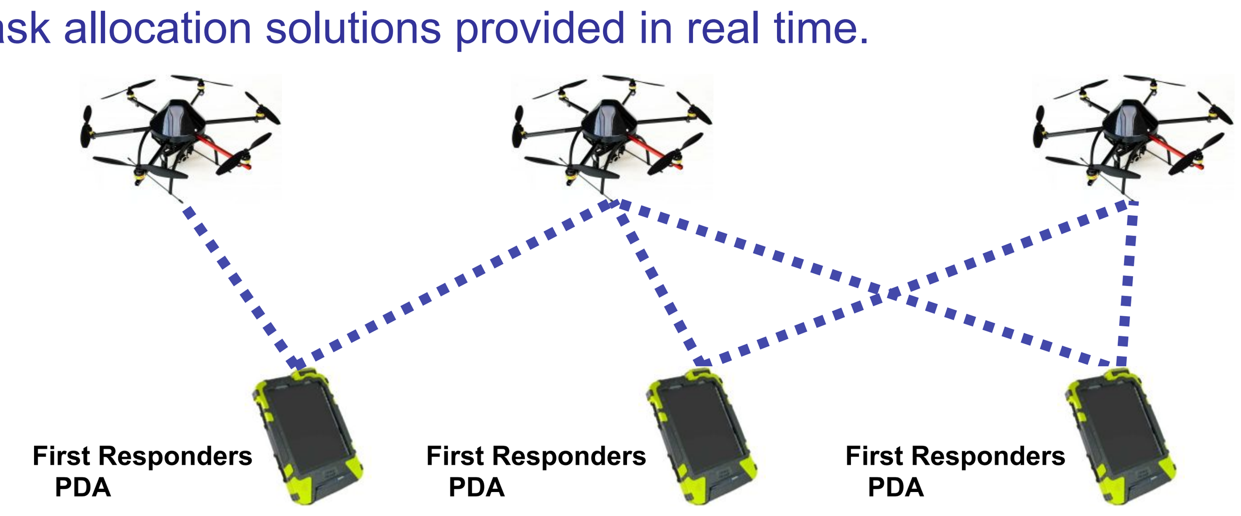
$$U_i(\mathrm{x}_i) = p_i u_i^{t-t_0}\left[1 - e^{-\lambda_i (t_2 - t_1)}\right]$$

- Model termination of task as a Poisson process and use the nominal duration to evaluate a task completion rate, $\lambda_i = 1/d_i$
- The time window of t_2-t_1 is found from the longest stay possible by the subset of UAVs and the soonest arrival time from the subset of UAVs.

Decentralised Coordination via Max-Sum

We apply the max-sum algorithm to achieve coordination:

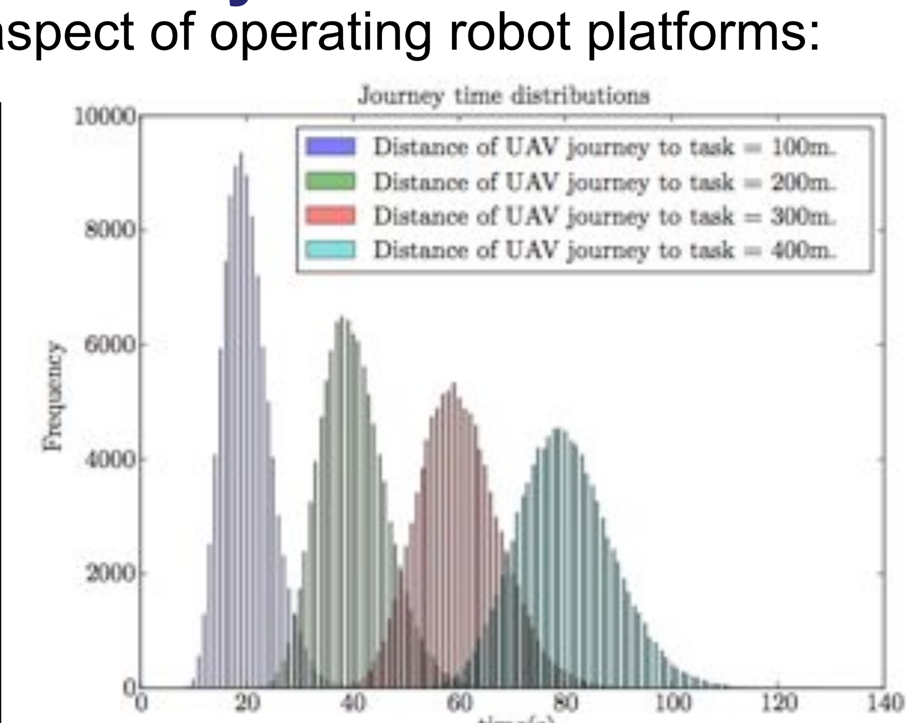
- Messages are passed over a factor graph.
- Decentralised algorithm provides benefits of efficient scaling with increasing number of agents, robustness to individual failure and adaptability to changes in agent numbers.
- Task allocation solutions provided in real time.



Uncertainty

Uncertainty is a fundamental aspect of operating robot platforms:

- Sensor information for localisation and velocity is known to certain bounds
- Actuator information liable to inaccuracy and wear
- External perturbations alter the dynamic performance of each individual platform
- We combine these factors and simulate this uncertainty; travel times are now represented as Gaussian distributions



Effects of Uncertainty

With travel times now represented by Gaussian distribution, the utility function also becomes a Gaussian distribution:

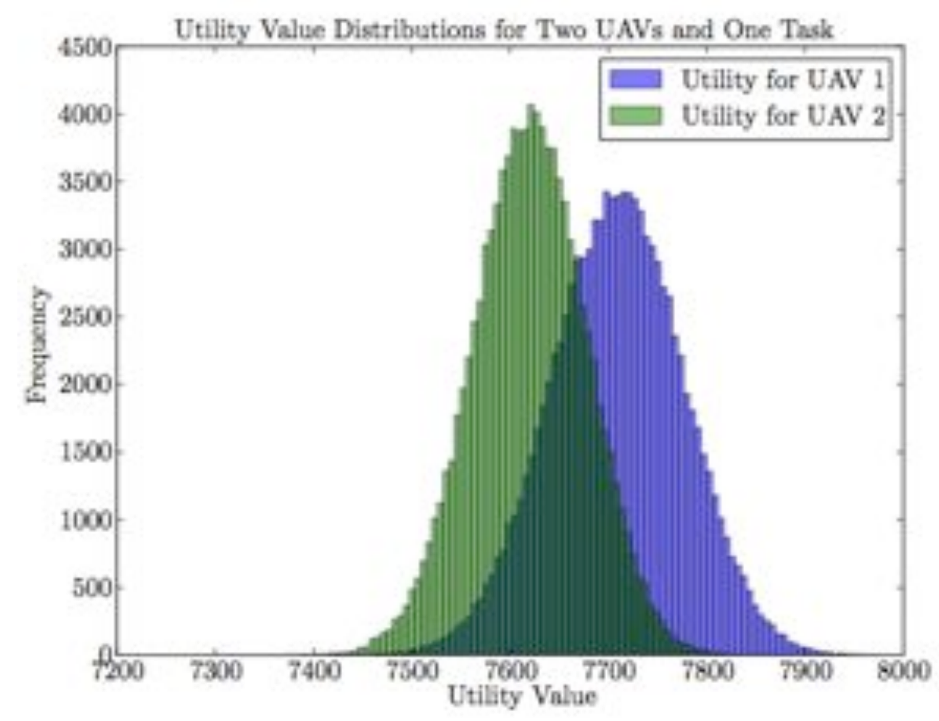
- We found the analytical solution to the utility distribution.
- Specifically we have equations for mean and variance of utility given knowledge of the same parameters as the original utility function.

$$E[U] = \mu_U = p_i u_i^{t-t_0}\left(1 - \frac{e^{\lambda\mu_{t_1}} e^{\lambda^2\sigma_{t_1}^2/2}}{e^{\lambda t_2}}\right)$$

$$\sigma_U^2 = p_i^2 u_i^{2(t-t_0)}\left(\frac{e^{2\lambda\mu_{t_1}} e^{\lambda^2\sigma_{t_1}^2}}{e^{2\lambda t_2}}\left(e^{\lambda^2\sigma_{t_1}^2} - 1\right)\right)$$

Uncertain Utility

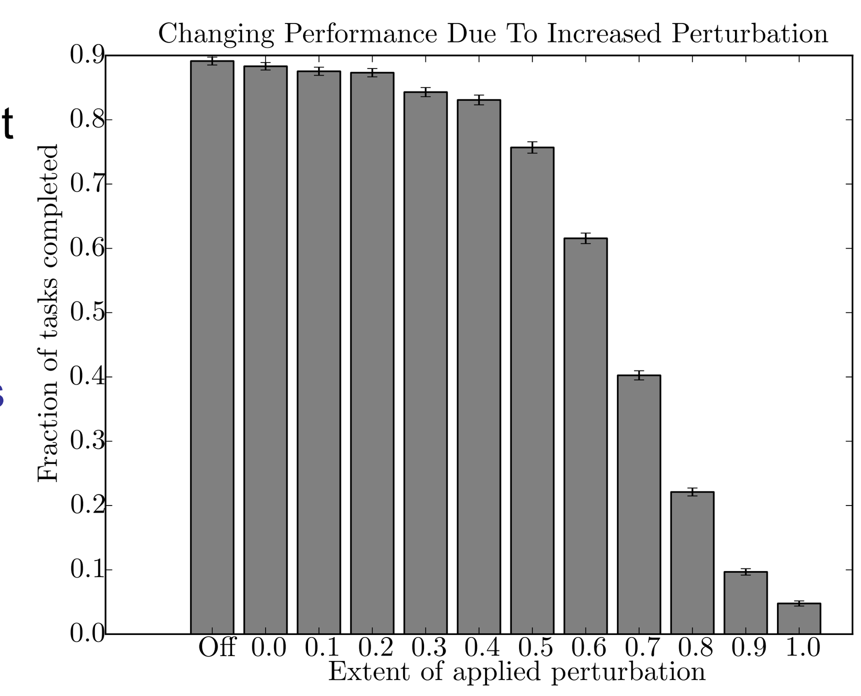
- The value obtained for each run of the max-sum can be different
- The optimal variable assignment obtained can vary
- This results in uncertainty in decision process



Impact Assessment

We implemented a test environment in which to assess the impact of simulated uncertainty on UAV team performance.

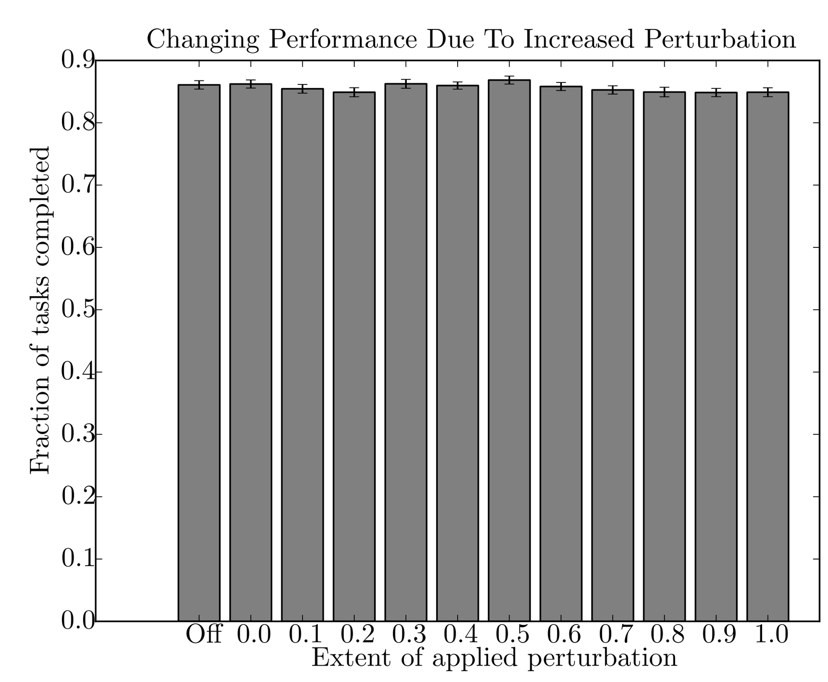
- Max-sum achieves almost 90% task completion before all UAVs have depleted battery life.
- As the extent of perturbation is increased the completion rate drops, the lowest performance being only 4% completion.



Initial Improvements

We have used the utility distribution expectation value in message passing.

- This results in consistent variable assignments and as such provides improved performance.
- This method ignores the full profile of the utility distributions and as such does not account for all attitudes to risk.



Future work

For future work we intend to:

- Develop novel decision protocols with regards to maximum utility distributions
- Extend the resulting form of the max-sum algorithm in order to provide solution quality guarantees

Field tests at the Australian Centre for Field Robotics:

- Run our novel coordination algorithms on real world platforms
- Apply coordination on UGVs restricted to defined paths.
- Coordinate joint activities of UAVs and UGVs
- Test performance for completing homogeneous and heterogeneous tasks.

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