Robust, Resilient, and Long-term Multi-Robot Autonomy

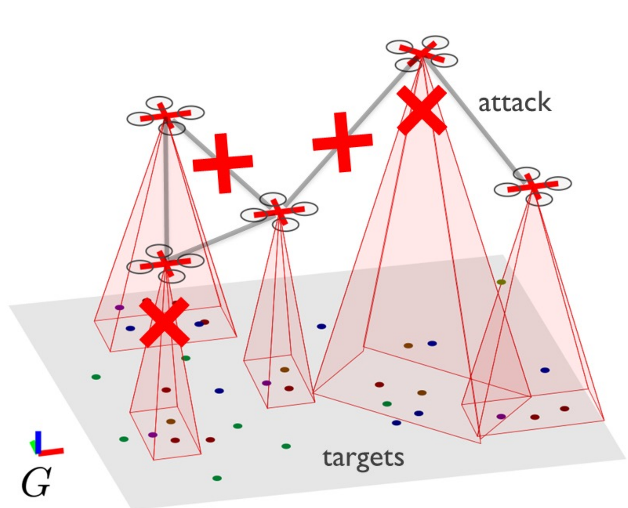
Lifeng Zhou, Drexel University

Design algorithms and build systems to enable **robust, resilient, and long-term operation of multi-robot systems** for tasks such as environmental monitoring, surveillance, reconnaissance, search and rescue, and urban mobility.

Resilient multi-robot coordination

Proactive resilient coordination to withstand attacks

1. Formulate game-theoretic problems between a robot team and an attacker.
2. Design resilient approximation algorithms to ensure good team performance even though some robots are attacked.



robot trajectory set; adversary removal set

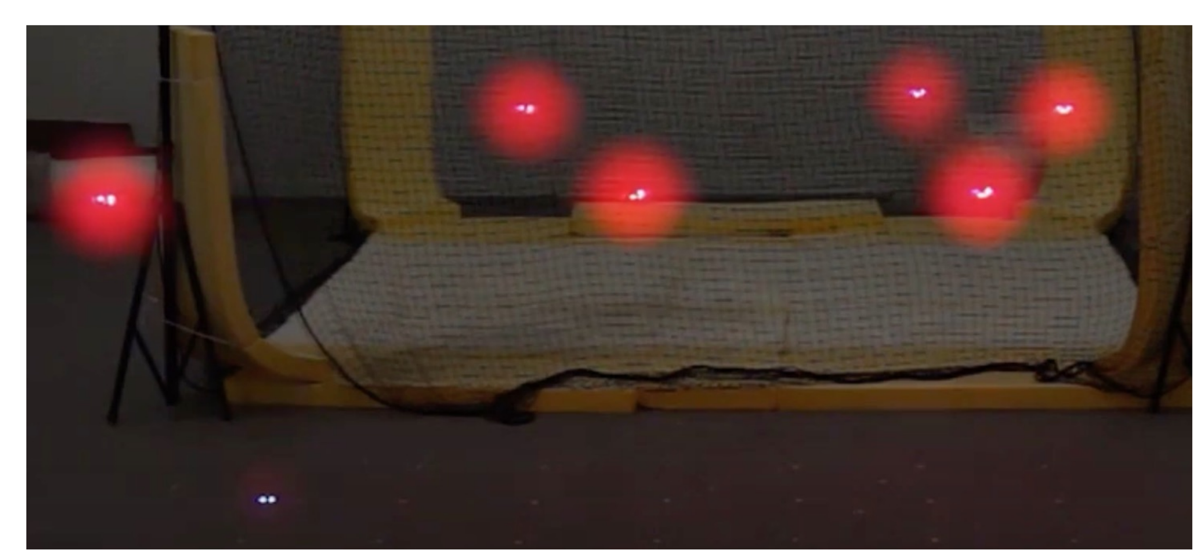
$$\max_{\mathcal{S}\subseteq\mathcal{X}} \min_{\mathcal{A}\subseteq\mathcal{S}} f(\mathcal{S}\setminus\mathcal{A})$$

$$\mathcal{S}\in\mathcal{I};\ |\mathcal{A}| = \alpha \leq N$$

num of attacks; num of robots

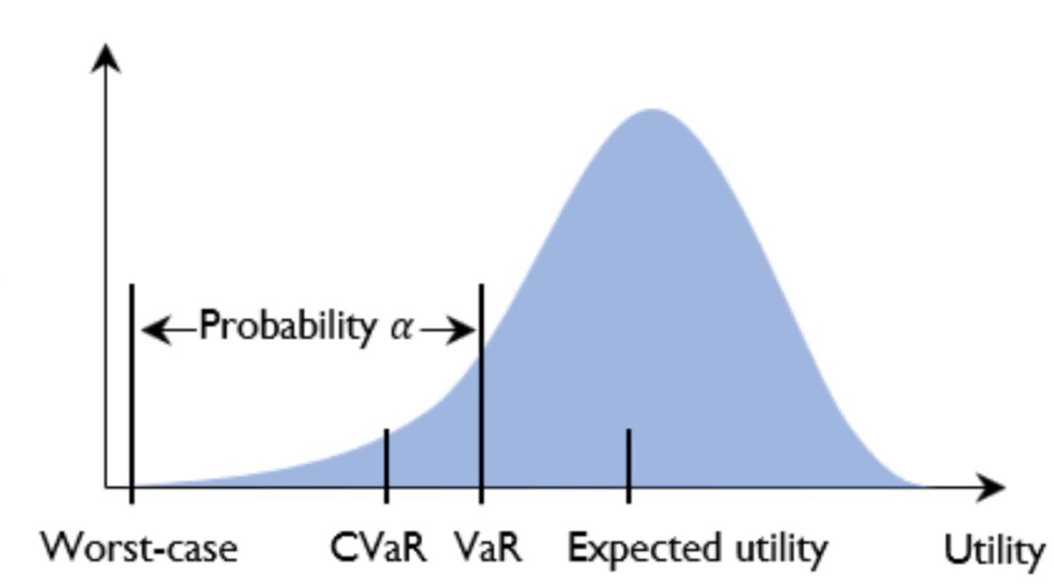
Reactive resilient coordination to recover after failures

1. Formulate a connectivity-aware optimization problem with the task performance as the objective and connectivity as the constraint.
2. Design a two-step optimization approach that utilizes a greedy algorithm and the control barrier function to enable robots to adaptively recover from failures.



Risk-aware multi-robot coordination

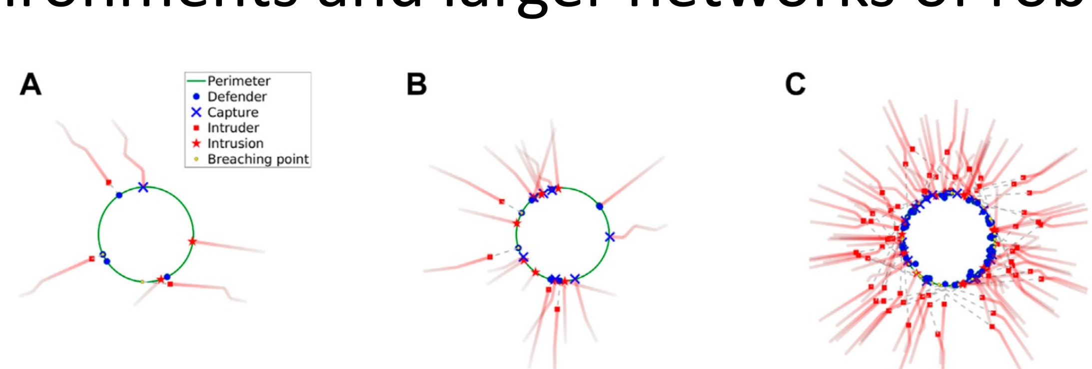
1. Formulate a risk-aware optimization problem using the Conditional-Value-at-Risk (CVaR) as the risk measure to bridge the gap between the high-level ideas of risk-awareness and the low-level specific planning for the robots.
2. Design a polynomial-time algorithm that gives a bounded approximation for CVaR-based combinatorial optimization.
3. Design a multi-objective optimization scheme that adaptively balances maximizing performance and minimizing risk.



Long-term multi-robot operation

Graph neural networks for scalable and large-scale coordination

1. Use GNN as a tool for synthesizing decentralized planning strategies which are trained to imitate centralized experts.
2. Transfer to larger-scale scenarios such as larger environments and larger networks of robots.



Snapshots of simulated perimeter defense using GNN for three different team sizes

Parsimonious communication strategies to reduce communication costs

1. Design a ``who to communicate with" strategy by forming robot subteams so that robots communicate within subteams instead of communicating with all the other robots.
2. Design a ``when to communicate" strategy that decides when a robot in the team should communicate to seek up-to-date information and when it is safe to operate with possibly outdated information.