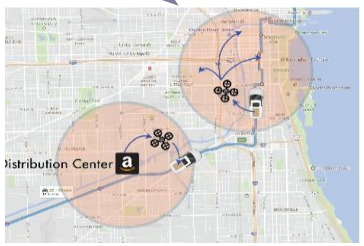
SYNDROME: SYNergetic DROne Delivery Network in MEtropolis

Naira Hovakimyan[†] , Lavanya Marla[†] , Marco Pavone[‡] , Srinivasa Salapaka[†] , Ranxiao Wang[†] , and Xiaofeng Wang[§]
[†]University of Illinois at Urbana-Champaign, [‡]Stanford University, [§]University of South Carolina

Motivation

The rapid growth of e-commerce demands has resulted in increased traffic of delivery trucks while **slowing down the pace** of delivery operations

Dispatch a package over the delivery network

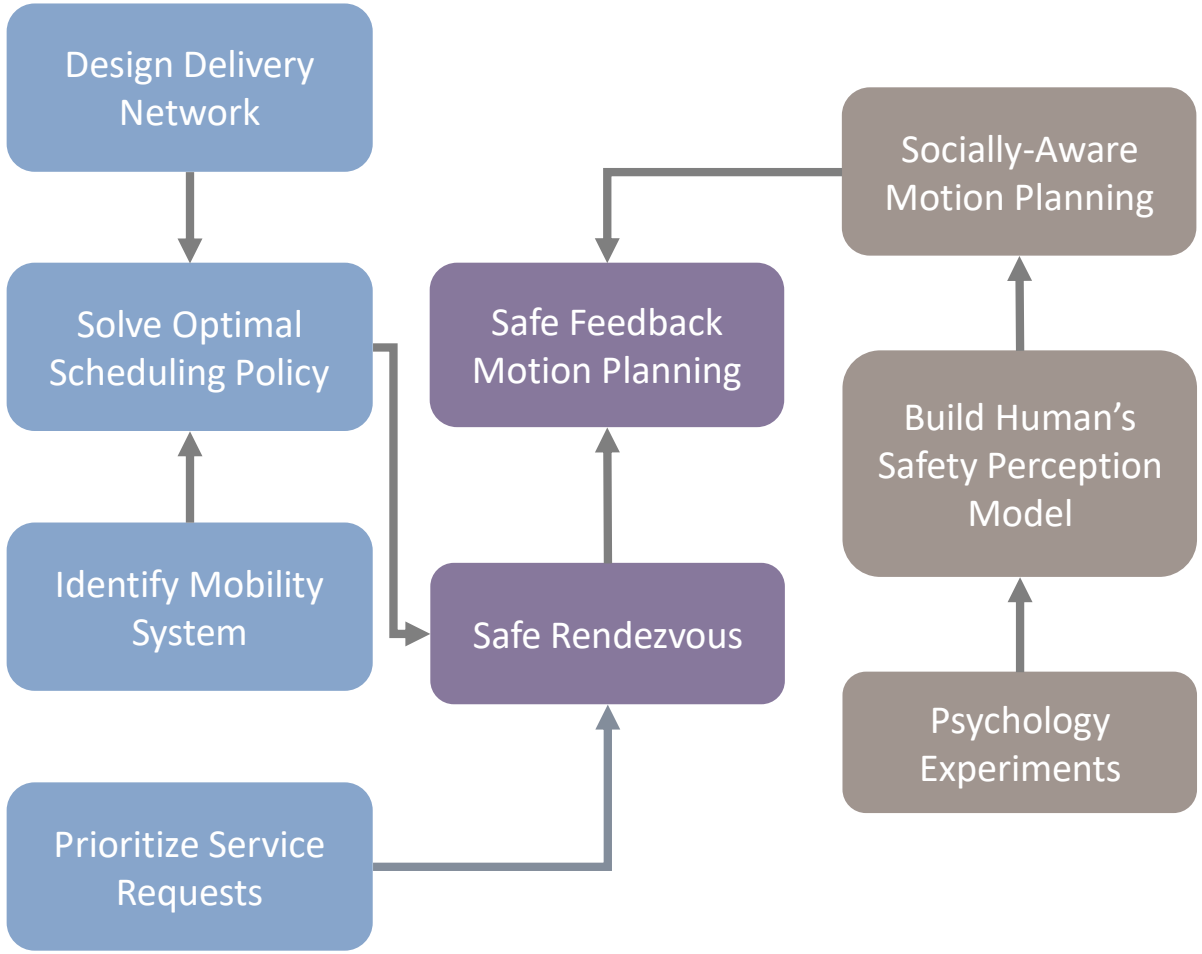


Use space on a ground vehicle's roof

Fly last-mile to the target position

The proposed delivery network is comprised of **autonomous flying robots** and **existing transport networks** (public and private ground vehicles).

Technical Approach



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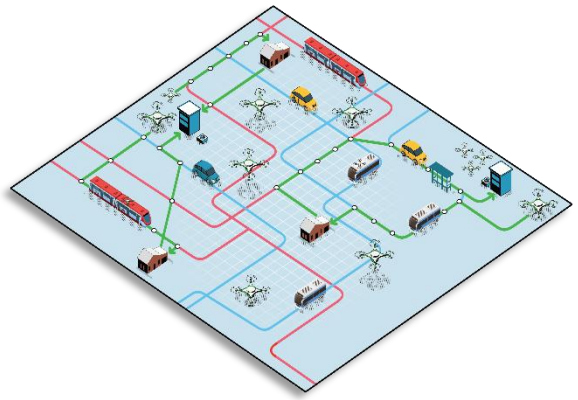
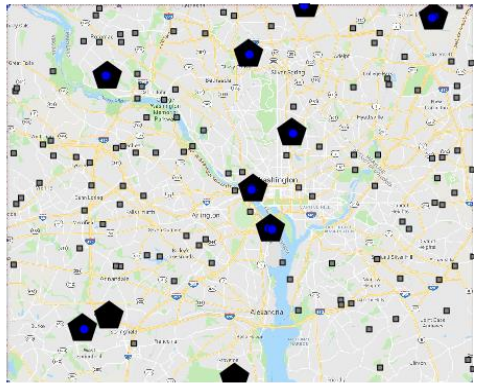
Large-Scale Drone Delivery Network





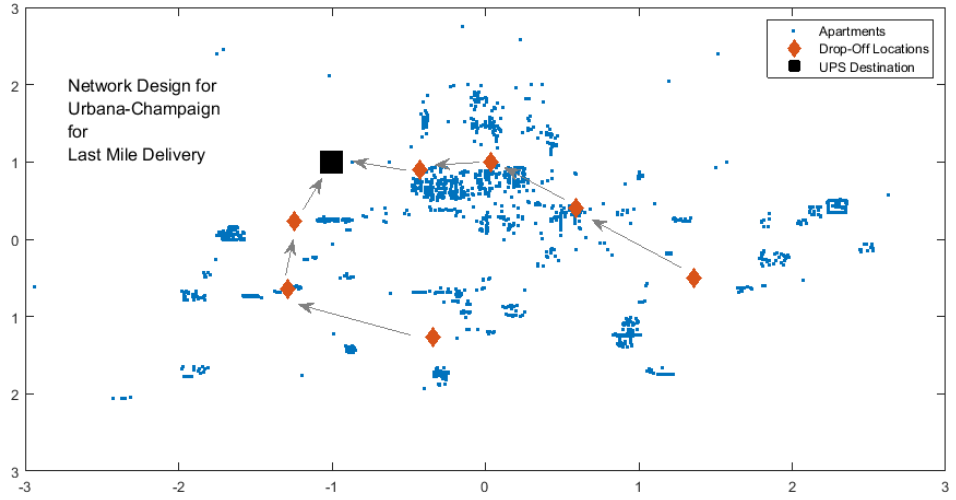
S. Choudhury, K. Solovey, M. Kochenderfer and M. Pavone, "Efficient Large-Scale Multi-Drone Delivery Using Transit Networks," ICRA 2020: 4543-4550.

An efficient and scalable framework for multi-drone delivery while utilizing public transit network over large urban areas.

- Assigns drone routes to deliver packages while **avoiding conflicts between drones**;
- Strives to minimize the overall delivery time of all the packages in the system.

Optimized Facility and Path Optimization

Srivastava, Amber, and Srinivasa M. Salapaka. "Simultaneous Facility Location and Path Optimization in Static and Dynamic Networks." IEEE Transactions on Control of Network Systems7.4 (2020): 1700-1711



A framework for simultaneously solving Facility Location and Path Optimization

- Considers both static and dynamic spatial networks;
- A novel stage-wise viewpoint of the paths to design the decision variable space;
- Optimization via **Maximum Entropy Principle**.

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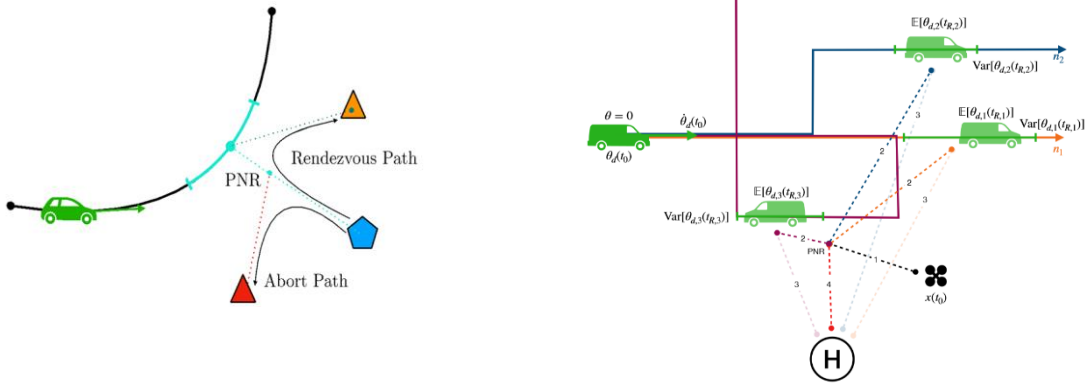
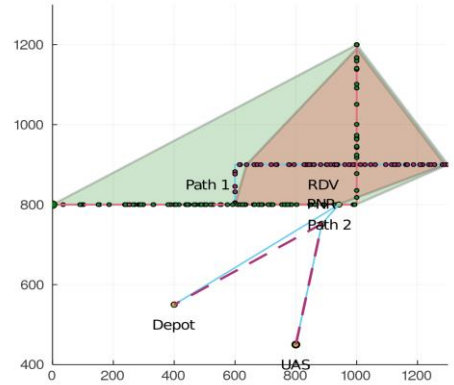
Risk Sensitive Rendezvous





A computationally tractable algorithm for **risk-aware rendezvous planning**

- Planning over multiple possible paths;
- Sampling based method relying on cross-entropy information updates.

G. Haberfeld, A. Gahlawat, and N. Hovakimyan, "Safe Sampling-Based Air-Ground Rendezvous Algorithm for Complex Urban Environments," in preparation for ICUAS 2021

Socially-Aware Motion Planning

A motion control framework for a flying drones that takes into account **the safety perception of humans in close proximity**

- Human's safety perception is predicted based on data collected from physiological experiments in a virtual reality (VR) environment;
- The predicted safety perception is incorporated in optimal control of the robot's motion based on model predictive path integral (MPPI) control;
- Generates perceived-safe motion of the robot online, accounting for changes in the environment in real time.

H. J. Yoon, P. Zhao, C. Tao, C. Widdowson, R. F. Wang, N. Hovakimyan, and E. Theodorou, "Socially Aware Motion Planning for a Flying Robot with Model Predictive Path Integral Control," ICRA 2019 Workshop.

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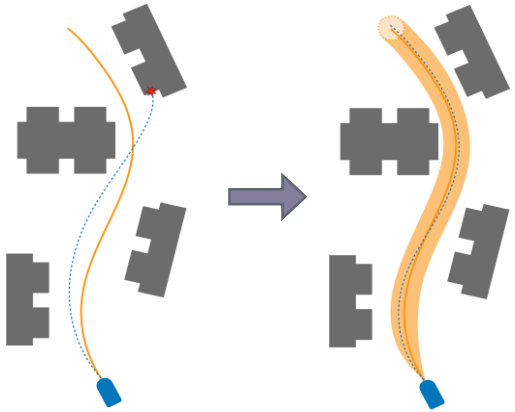
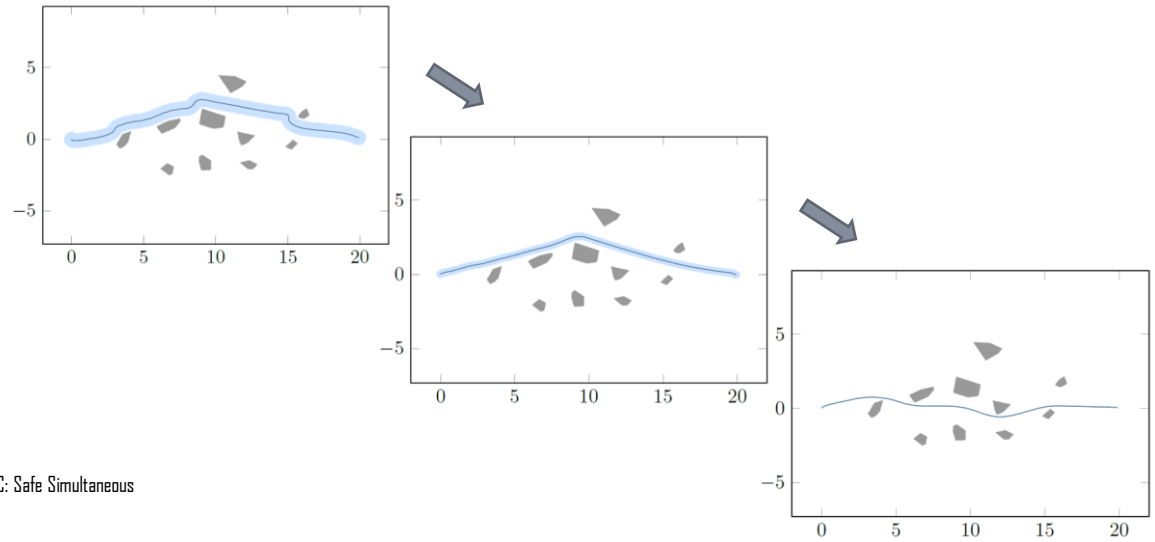
Safe Learning-based Control



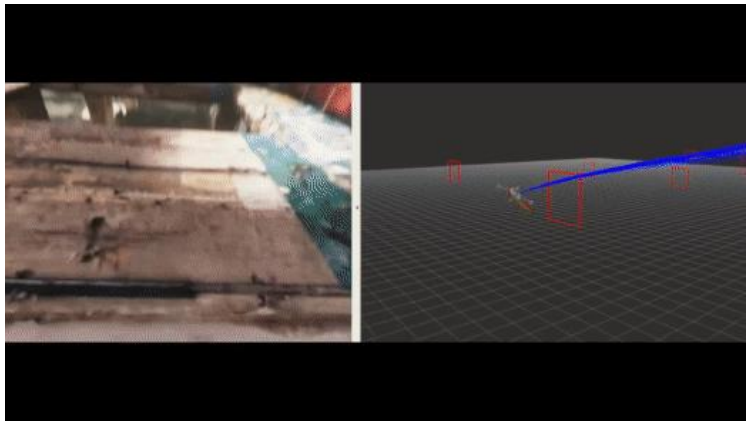


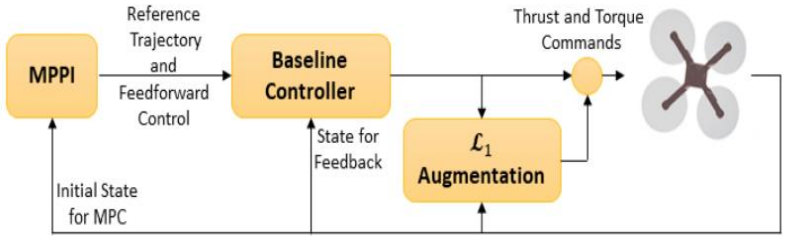
A. Gahlawat, A. Lakshmanan, L. Song, A. Patterson, Z. Wu, N. Hovakimyan, and E. Theodorou, "S2LC: Safe Simultaneous Learning and Control," under review at L4DC 2021

Planner-agnostic approach for certified safety

- Contraction theory with $\mathcal{L}_1$ adaptive control;
- **Safety decoupled from Bayesian learning**;
- Guaranteed safety in the form of tubes for assured planning.

Robust & Agile Control of Multirotors





Pravitra, J., Ackerman, K. A., Cao, C., Hovakimyan, N., and Theodorou, E. A. L1-Adaptive MPPI Architecture for Robust and Agile Control of Multirotors. International Conference on Intelligent Robots and Systems, 2020.

A sampling-based predictive control architecture

- Model Predictive Path Integral (MPPI) control solves nonlinear MPC in real-time;
- $\mathcal{L}_1$ adaptive control robustifies the architecture;
- System performance behavior mirrors **nominal dynamics** considered by MPPI.

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