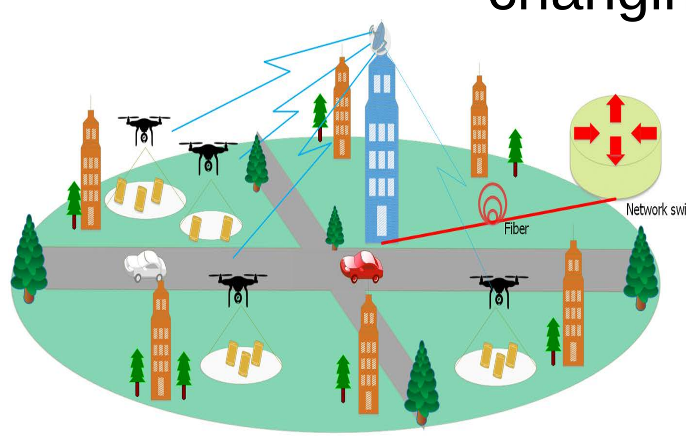
Trajectory-Based Cyber-Physical Networks (TCN): Theoretical Foundation and a Practical Implementation

Award Number: 1932326, Award Date: Oct 1, 2019- Sept 30, 2022

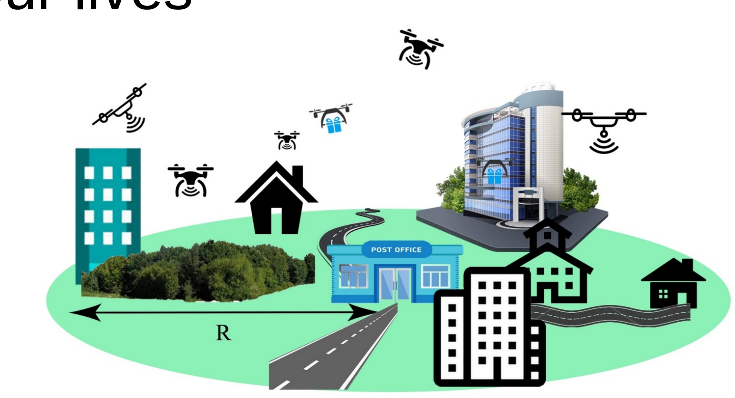
Hossein Pishro-Nik
pishro@umass.edu
University of Massachusetts, Amherst

Introduction

TCNs such as Unmanned Aerial Vehicles (UAVs) changing our lives



Aerial base stations



Package delivery

Agriculture

Surveillance

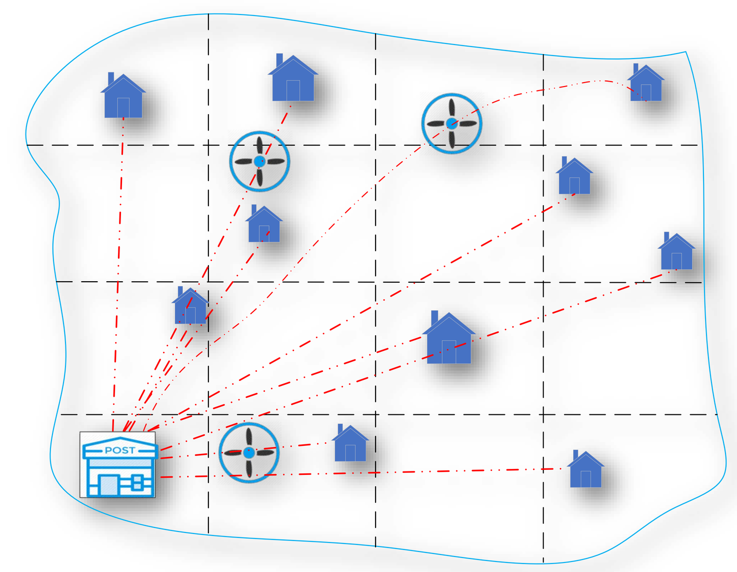
- UAVs move along **non-deterministic paths (trajectories)**
- Trajectory-Based Cyber-Physical Networks (TCN) is **interdisciplinary**, employs techniques:
  - Probability
  - Stochastic geometry
  - Wireless networks
- **Challenge:**
- How to decrease the number of UAVs used for several applications?
- How to efficiently exploit UAVs in multiple applications simultaneously?

Broader Impact

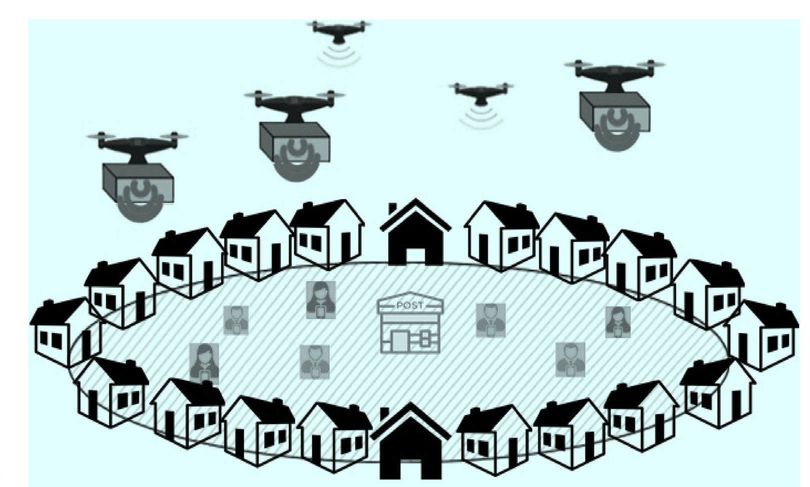
The proposed project has the potential to improve understanding, modeling, and design of several emerging real-life systems, especially UAS.

Multipurpose Drones for Coverage and Transport Applications

- **Goal:** Implementing drones for simultaneous efficient wireless communication and package delivery

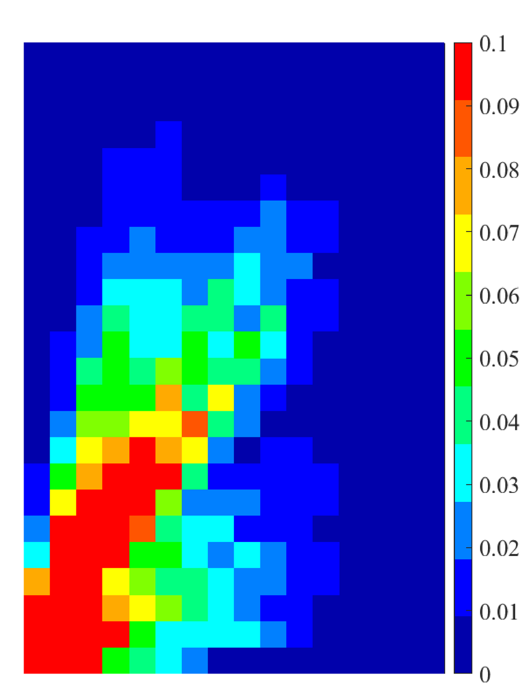


Practical case



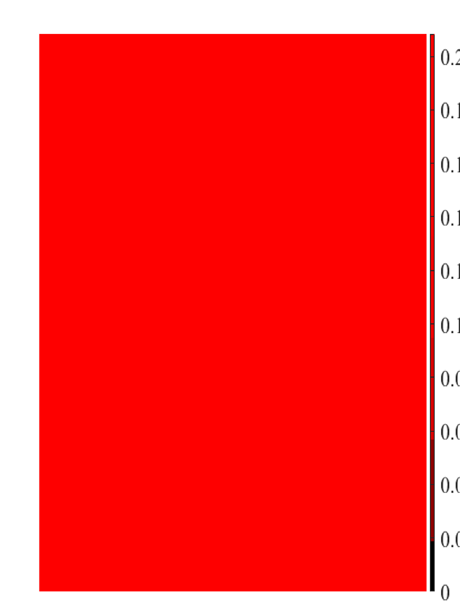
Ideal case

- **Approach:** Designing simultaneously time-efficient drone delivery and uniform wireless coverage .
- **Delivery efficiency:** $\eta = \frac{T_m^*}{T_m(A)}, 0 \le \eta \le 1$
- **Uniform coverage:** percentage of the time each region is covered by drones over time



Benchmark algorithm: simple straight trajectory with constant speed

Heat map of the number of drones in the UMASS Amherst Campus (practical case#1)



Proposed algorithm: Variable speed with adjustable trajectories

- **Communication access delay:** $T_{Delay} = \frac{\sum_{k=1}^{K} \delta_k}{K}$

Communication Delay, Delivery Time, and Power Efficiency Evaluation

Table I: Communication delay when 1000 Packages are delivered

	Benchmark algorithm	Proposed algorithm
UMASS community	31.68	16.06
Union Point community	Inf	19.12

Table II: Time efficiency to deliver 1000 Packages with 10 drones

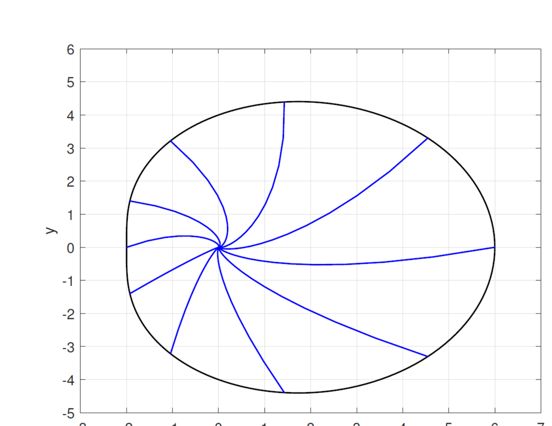
	Transport Efficiency	fraction of packages (average) with delivery time >30 mins
UMASS community	1	0.006
Union Point community	0.87	0.012

Table III: Propulsion energy consumption to deliver 10 packages

	Total energy consumption(J)		Energy Efficiency
	Benchmark algorithm	Proposed algorithm	
UMASS community	1910K	1983K	0.96
Union Point community	1750K	2050K	0.85

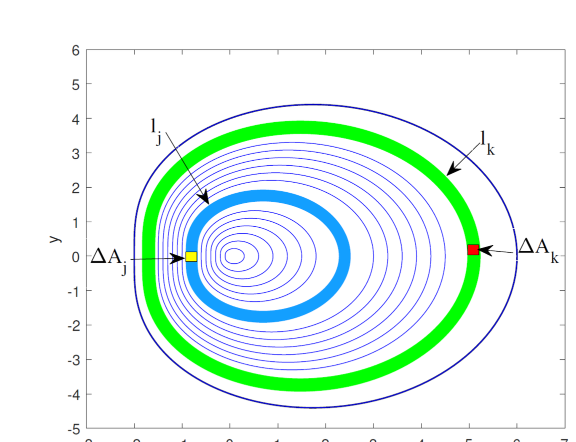
UAV Trajectories for Uniform Coverage in Convex regions

- **Goal:** Design general trajectories for general convex regions



General Spiral trajectories family

Uniform and ergodic trajectories



General Oval trajectories family