Drone Simulation

CSC 36000 — Distributed Systems

12/15/2025

Presented by

Rivaldo Lumelino
Alexandr Voronovich

Motivation & Problem

Communication is unreliable
Title

Network conditions vary (urban, suburban, rural)
Title

Drones must remain safe and autonomous
Title

Decisions should be interpretable
Title

Core Question:

How do different communication networks affect coordination, safety, and task completion in multi-drone systems?

System Overview

1 **Multiple drones (agents)** in a shared 2D environment

2 **Distributed communication** with delays and packet loss

3 **Local sensing** as a backup when communication fails

4 **Task-based behavior** (pickup → delivery)

Each drone acts **independently**, without centralized control

Agent Design (What a Drone Can Do)

Each drone has:

Position `(x, y)` and velocity `(vx, vy)`

Communication memory (recent neighbor positions)

Local sensor range (5 meters)

A task state machine:

A task state mchine:

- `IDLE`
- `GO_TO_PICKUP`
- `GO_TO_DROPOFF`

Key idea:
Drones make decisions using **only local information**

Communication Models (Baseline)

Network	Characteristics
V2X	Near-real-time, very low loss
MQTT	Higher delay, moderate loss
Urban	Medium delay, low loss
Suburban	Medium delay, moderate loss
Rural	High delay, high loss

These models simulate real distributed system conditions.

Key Challenges We Faced

Unreliable communication

Stale or delayed information

Task coordination without central control

Collision risk

Uninterpretable agent behavior

How We Solved Them (Contributions)

Contribution 1 — Adaptive Communication Fallback

- Sensors activate when messages fail
- Prevents collisions and deadlocks

Contribution 2 — Smoothed Neighbor Memory

- Short history prevents jitter from delayed packets

Contribution 3 — Interpretability Layer

- Human-readable decision logs
- Quantitative explanation metrics

Contribution 4 — Task-Oriented Swarm Control

- Realistic pickup/drop logistics
- Fully decentralized execution

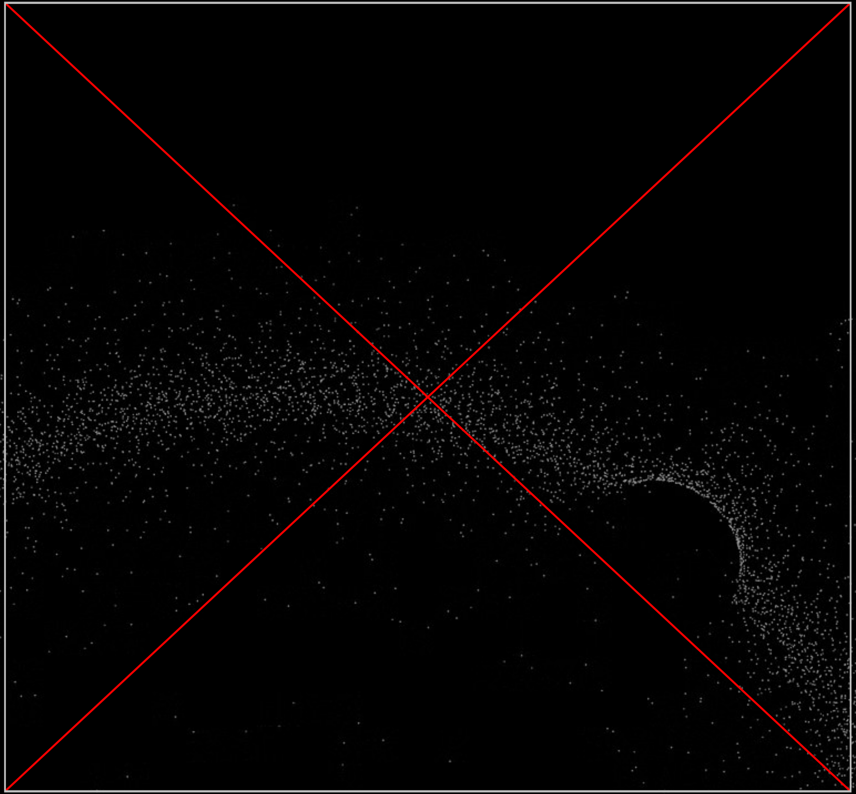
Result

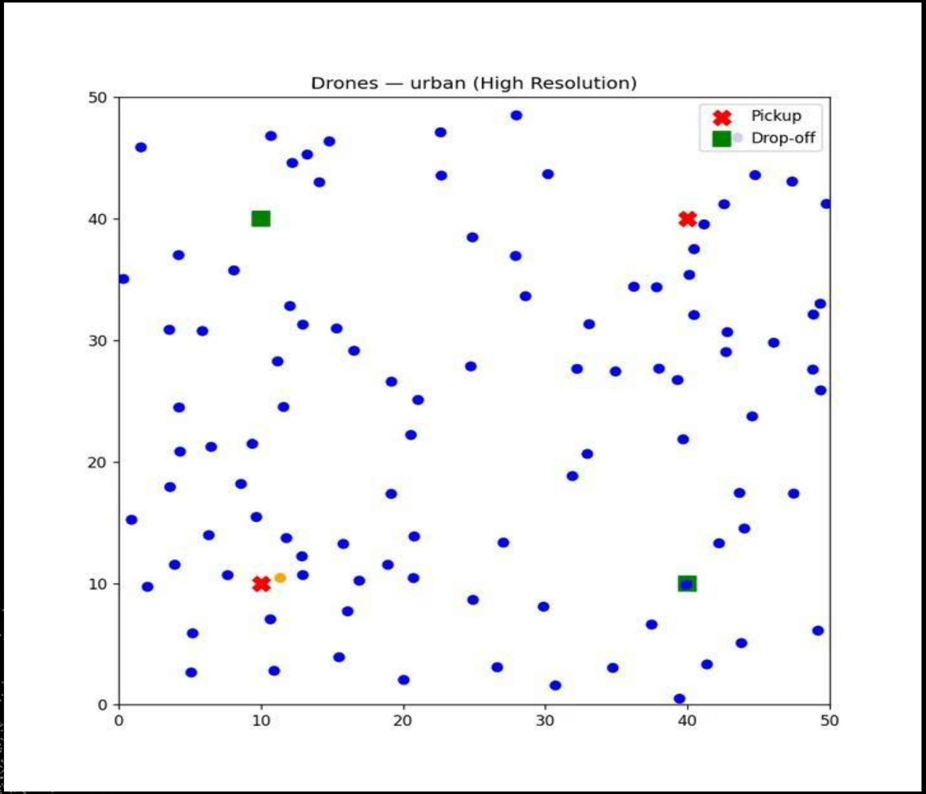
```
=== SINGLE RUN SUMMARY (rural) ===
Network type:      rural
Total steps:       50
Agents:            8
Messages sent:     2800
Messages received: 902
Delivery rate:     0.32
Average delay:     7.39 steps
Collisions:        0
Sensor fallbacks:  0
Interpret events:  1202
Dropped stale:     673
Tasks completed:   0

=== SAMPLE INTERPRETABILITY LOGS (first 5 steps) ===

Time step 1, 24 events
[Agent 0] New task: go to pickup at (10, 10)
[Agent 0] No messages and no nearby drones → slowed down. Velocity (-0.5591187559186066, 0.17853136775181744) -> (-0.11,0.04)
[Agent 0] Steering toward task goal (10, 10). (-0.11182375118372133, 0.03570627355036349) -> (-0.44,0.17)
[Agent 1] New task: go to pickup at (10, 10)
[Agent 1] No messages and no nearby drones → slowed down. Velocity (0.6188609133556533, -0.987002480643878) -> (0.12,-0.20)

Time step 2, 16 events
[Agent 0] No messages and no nearby drones → slowed down. Velocity (0.015363349208650456, -0.78717835440459) -> (0.00,-0.16)
[Agent 0] Steering toward task goal (10, 10). (0.0030726698417300915, -0.15743567088091803) -> (-0.37,0.05)
[Agent 1] No messages and no nearby drones → slowed down. Velocity (0.25060038713283506, 0.6833386963449342) -> (0.05,0.14)
[Agent 1] Steering toward task goal (10, 10). (0.05012007742656702, 0.13666773926898684) -> (-0.36,-0.02)
[Agent 2] No messages and no nearby drones → slowed down. Velocity (0.015325763955268412, -0.6021777964705339) -> (0.00,-0.12)

Time step 3, 16 events
[Agent 0] No messages and no nearby drones → slowed down. Velocity (0.32374262390149044, -0.026657176691341045) -> (0.06,-0.01)
[Agent 0] Steering toward task goal (10, 10). (0.06474852478029809, -0.005331435338268209) -> (-0.33,0.15)
[Agent 1] No messages and no nearby drones → slowed down. Velocity (-0.6202042654647257, -0.5645982031716501) -> (-0.12,-0.11)
[Agent 1] Steering toward task goal (10, 10). (-0.12404085309294516, -0.11291964063433002) -> (-0.46,-0.18)
[Agent 2] No messages and no nearby drones → slowed down. Velocity (-0.8830334159854012, 0.47147435757808687) -> (-0.18,0.09)

Time step 4, 16 events
[Agent 0] No messages and no nearby drones → slowed down. Velocity (0.947674045274578, 0.49895522228707856) -> (0.19,0.10)
```

Result

Mode	DelivRate	AvgDelay	Collisions	SensorFB	ExplainEv	Dropped	Tasks
v2x	0.97	1.00	0	0	1263	0	0
mqtt	0.81	5.48	0	0	1231	0	0
urban	0.91	2.01	1	0	1254	0	0
suburban	0.84	3.99	0	0	1237	0	0
rural	0.32	7.39	0	0	1202	673	0

Simulation




Drones — urban (High Resolution)
Pickup
Drop-off
0
10
20
30
40
50
0
10
20
30
40
50

Future Work

- Increase number of drones (scalability study)
- Dynamic task generation
- Priority-based deliveries
- Learning-based policy optimization
- Real-world hardware deployment

Conclusion

We built a **robust, interpretable, distributed multi-drone system** that:

- Adapts to different network conditions
- Remains safe under failures
- Completes real tasks
- Provides transparent reasoning

This moves beyond simulation into **practical autonomous system design**.

Thank you

https://github.com/gizmo1547/Laika/tree/main

https://colab.research.google.com/drive/1uNz9UnVD6ye_g6YHMB02sG19JYGzVOpL#scrollTo=8c81bc22