



University of Missouri



RoutePEARL: Route Planner for Efficient Aerial and Road Logistics



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NSF PFI-TT Award TIP-2313887: Cloud-based Network-Aware Route Management Platform for Electric Truck and Drone Operations

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Experimentation: Objective and Setup



- RoutePEARL is a network-aware route planning platform for coordinating trucks and drones for efficient last-mile delivery
- Challenge: routes depend on both transportation and communication conditions, as drones and trucks may experience changing wireless links, network partitions, traffic, environmental conditions
- We are taking RoutePEARL from simulation to field experiments on AERPAW across three delivery modes or three envisioned topologies

1) Basic: electric truck only

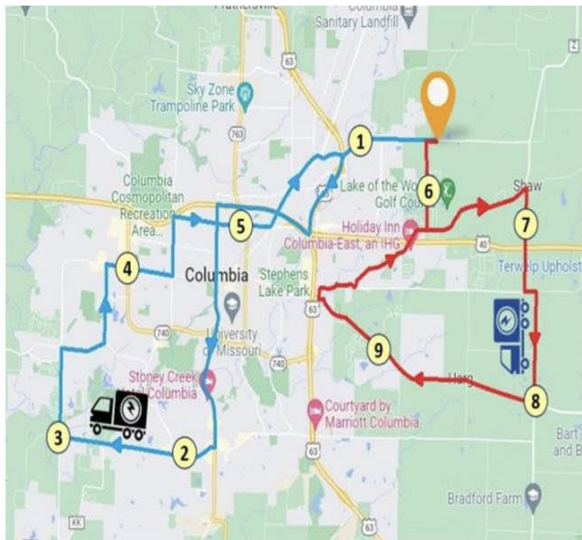
AERPAW rover (UGV) as the EV, with a large portable node

2) Intermediate: direct drone only

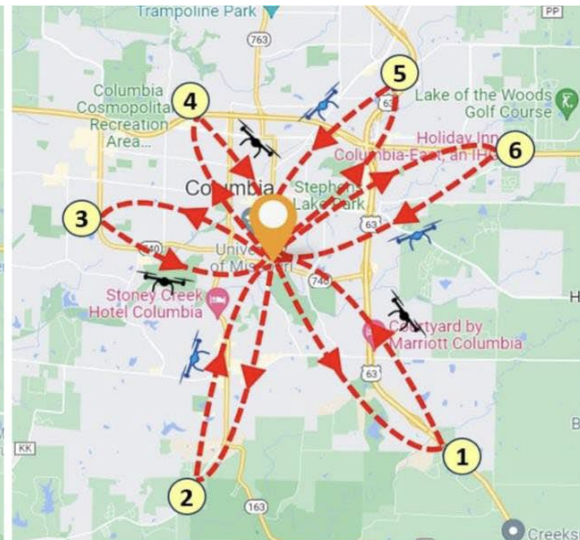
Small multicopter (SAM4) point-to-point

3) Advanced: hybrid truck-drone

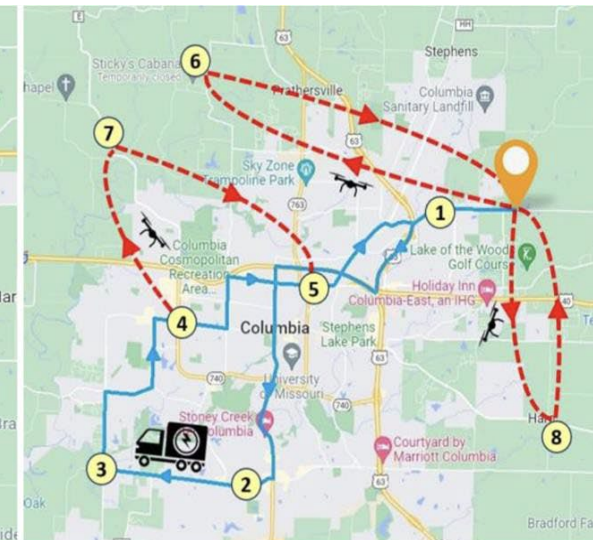
LAM6 + SAM4 + rover as one coordinated fleet



a) Electric truck-only delivery



b) Direct drone delivery

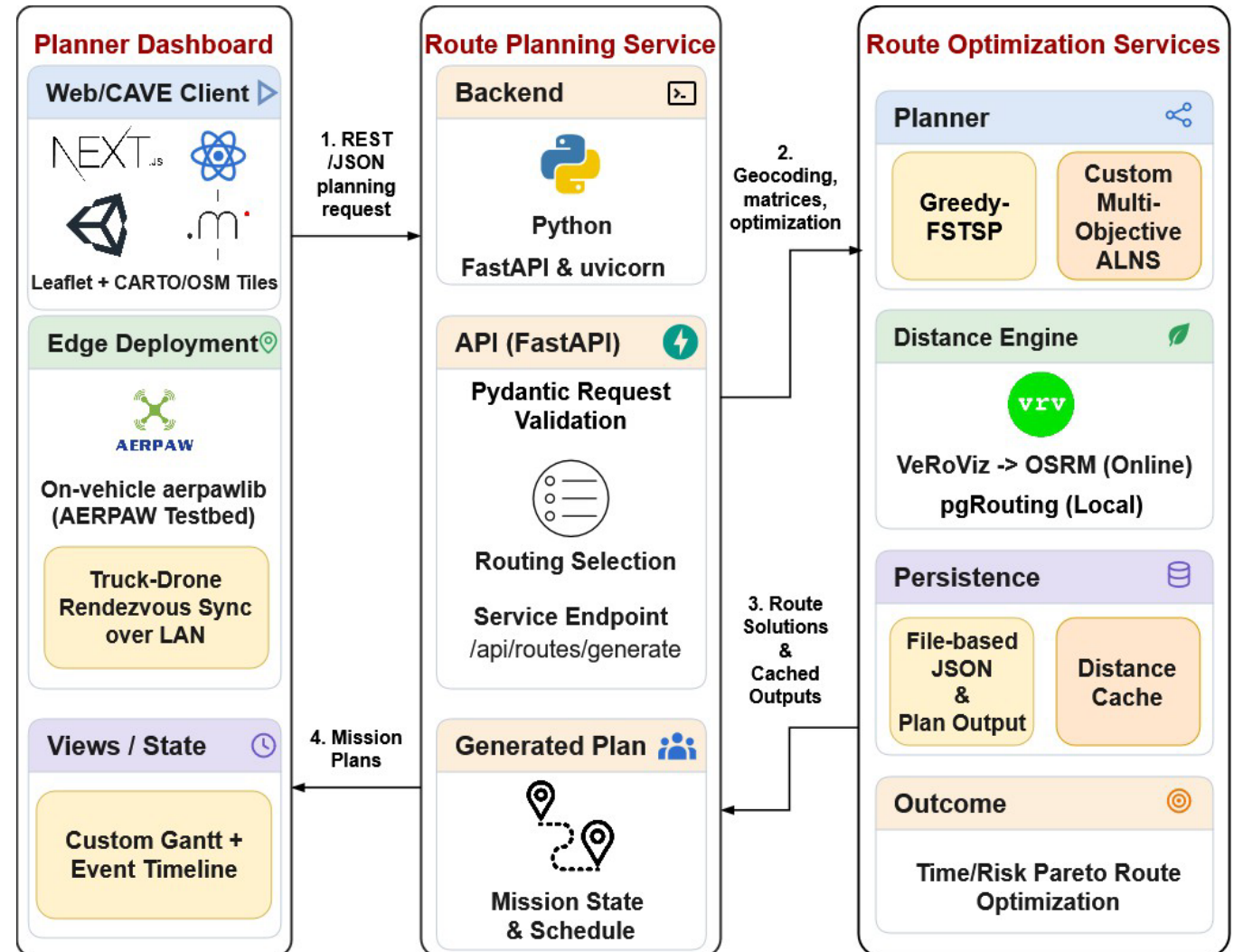


c) Hybrid truck-drone delivery

RoutePEARL Platform Architecture



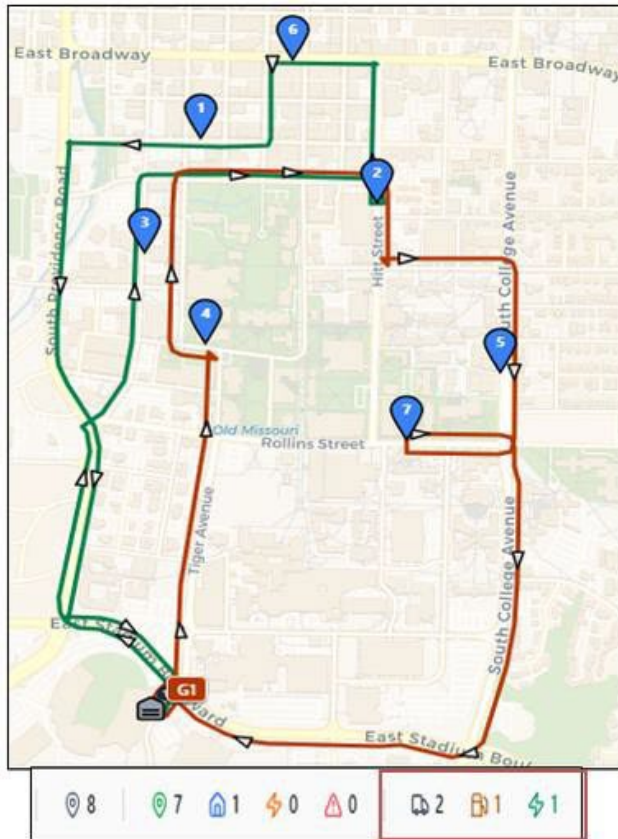
- Operators define delivery missions on a map (orders, depots, staging stations, no-fly zones), set up the fleet, and check per-vehicle Gantt and event timelines
- RoutePEARL generates routes through a common API using ALNS, FSTSP, or least-risk planners, with RL adaptation and GNN-guided pruning supporting route optimization



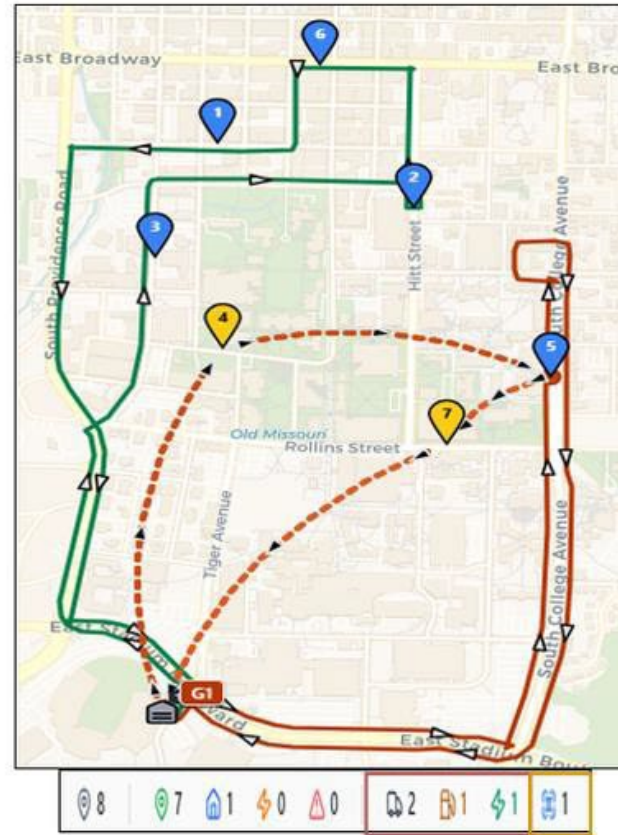
RoutePEARL Planner Dashboard



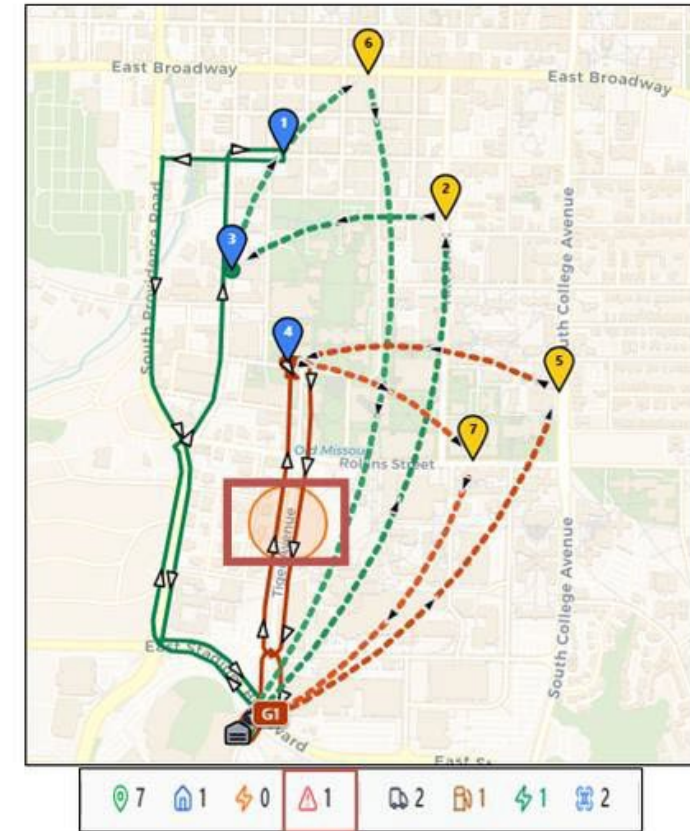
- Planner dashboard integrates route planning service, and route optimization services that run together on one edge device



Truck Only Route



Mixed Drone Allocation Route



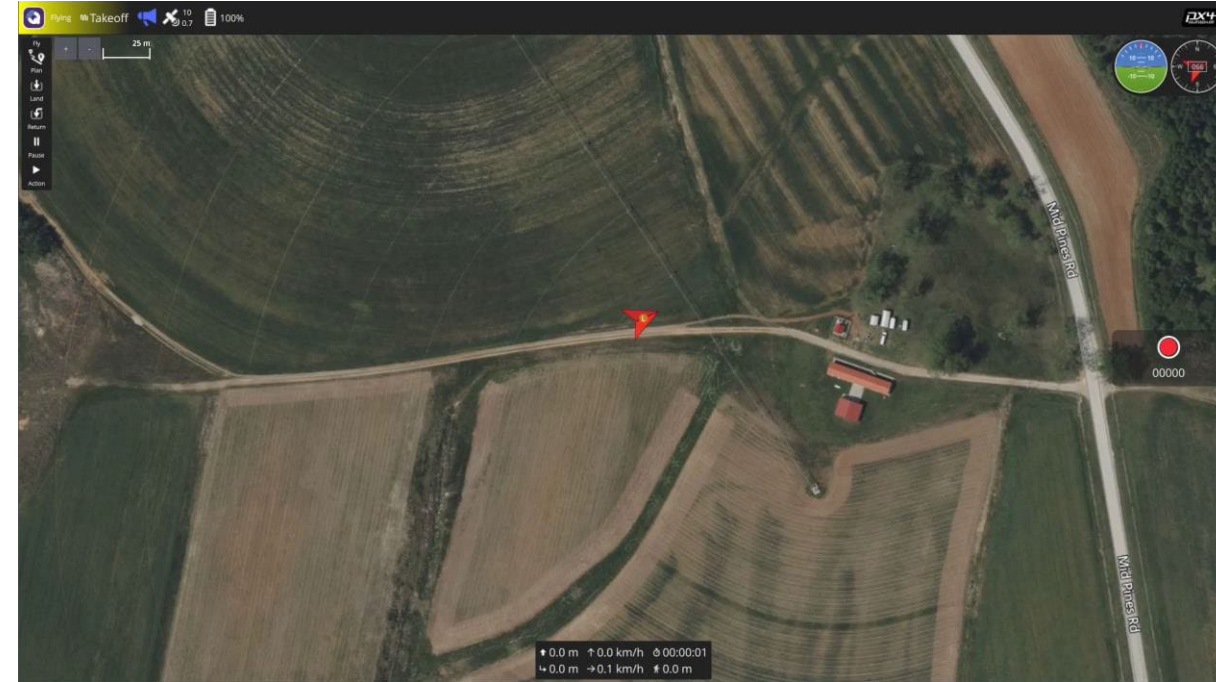
Drone-Flight Sensitive Zone

Map view of one mission: truck-only route, mixed drone allocation, drone-flight sensitive zone

Results and Outcomes on AERPAW



- We deployed RoutePEARL planners (meta-heuristic, MILP and RL) on AERPAW drones, rovers, and SDR-based wireless links across truck-only, drone-only, and hybrid delivery setups
- When the truck communication link was lost, the Q-learning planner re-routed the drone mission and achieved better path optimization than A*
- Basic, moderate, and advanced setups were exercised at Lake Wheeler
- Measured route distance, GPS, completion time, delivery success rate, resource utilization, throughput, packet loss, round-trip delay



Video: Lake Wheeler Road Field Site, NC State

RoutePEARL Edge Application Performance



Goal: Evaluate how efficiently RoutePEARL runs on an edge device using AERPAW resources as the delivery workload increases

Results:

- RoutePEARL planned routes for up to 20 orders in 8.4 seconds or less
- Complete application used only ~150 MB of memory, making it practical to run on an edge device
- Using locally cached route data, lookup time reduced from 26–125 seconds to only 1–2 milliseconds
- After the initial data was downloaded, RoutePEARL could continue planning routes without relying on a WAN connection

N (cust.)	FSTSP e2e (ms)	Least-risk e2e (ms)	ALNS e2e (s)	ALNS solve (ms)	Peak RSS (MB)
5	1038	834	2.93	519 ± 3	149
8	1812	1612	3.55	1171 ± 8	149
10	2331	1564	4.23	1436 ± 7	149
12	2600	2409	4.67	1731 ± 10	149
15	3478	2383	5.71	2505 ± 12	151
20	4641	4434	8.41	5004 ± 27	151

End-to-end latency per planning service, ALNS solve time, and peak memory

N	Cold fetch (OSRM/WAN)	Warm (cached/offline)
8	26.1 s	~1 ms
10	36.9 s	~1 ms
12	51.4 s	~2 ms
15	73.8 s	~1 ms
20	124.6 s	~2 ms

Distance-matrix acquisition: cold OSRM fetch versus local cached lookup

Setup: 12-core CPU / 64 GB RAM edge workstation, AERPAW Server using Routing Services

Missions around Columbia, MO with 1 depot, 1 staging station, N orders, and 2 drones; 8 runs per point

Why AERPAW as the Research Platform?



- Building on our FlyPaw work and other projects with the AERPAW team
- Realistic wireless and mobility conditions beyond simulation, including interference, fading, jamming
- Programmable 5G equipment for controlled tests of performance and resilience under uncertain conditions (e.g., DDoS floods, data poisoning)
- High-fidelity datasets of drone telemetry and traffic that improve routing model fidelity

FlyPaw: Optimized Route Planning for Scientific UAV Missions

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IEEE e-Science' 23

Federated Learning-enabled Network Incident Anomaly Detection Optimization for Drone Swarms

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ACM ICDCN' 25

Enhancing Drone Video Analytics Security Management using an AERPAW Testbed

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IEEE CNERT' 24

An Edge-Intelligent Decision-Support Application for Coordinated Truck-Drone Logistics

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Prior publications using AERPAW testbeds

How AERPAW Supports Our Work

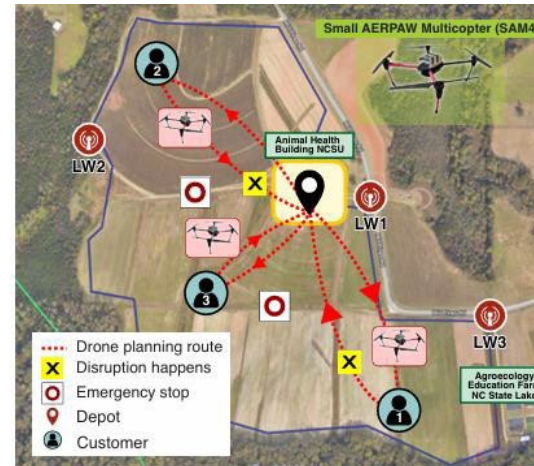


- Digital Twin environment emulates AERPAW radio and flight conditions, so RL policies are validated before field flights and field runs feed back into simulation
- Portable and Fixed Radio Nodes run trained policies onboard and configure programmable 4G/5G/Wi-Fi links with varying packet-loss regimes
- Fault/hazard injection tools and telemetry logging for validating truck-drone routing
 - ArduPilot, QGroundControl, and MAVProxy connect RL decisions to UAV control
 - Large and small multicopters and a rover node emulate multi-drone topologies

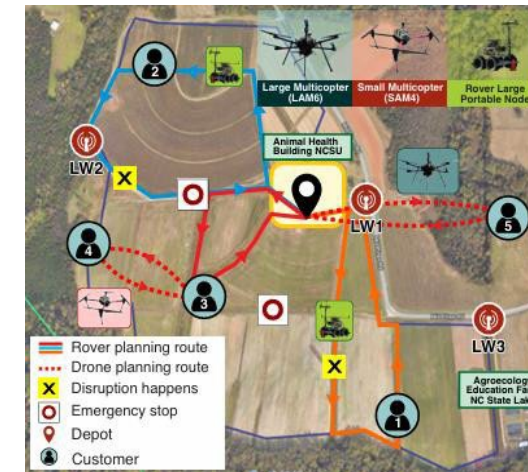
Envisioned AERPAW Topologies



(a) Electric Truck Only



(b) Direct Drone Only

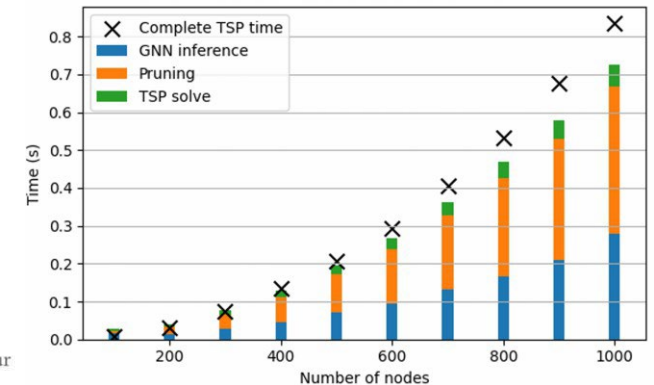
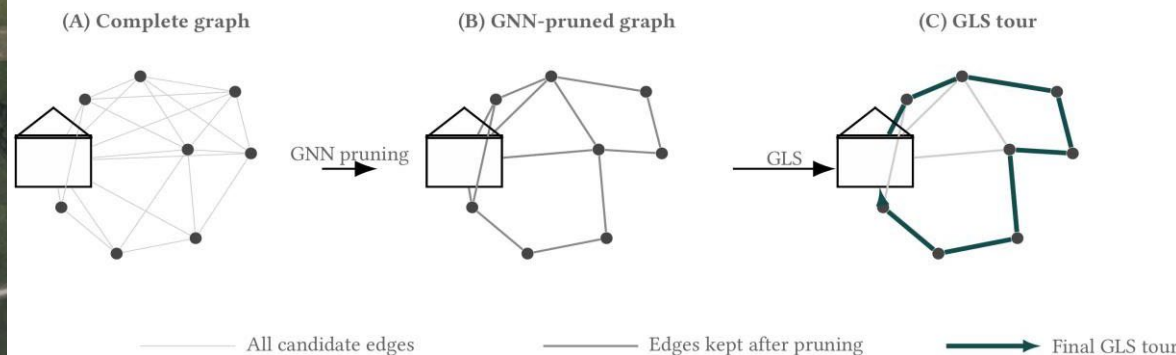


(c) Hybrid Truck-Drone

How AERPAW Supports Our Work



- AERPAW's AADM Challenge defined the mission: a UAV collects data from multiple ground stations and returns to base within fixed energy and time budgets
- Lightweight Graph Attention Network prunes low-utility flight edges; Guided Local Search finds the final route directly on edge hardware, without requiring centralized solver
- On a 1,000-node graph, our approach was 13.2% faster than centralized OR-Tools while producing routes only 0.7% longer.



Hybrid GNN-GLS routing pipeline for AADM-style UAV Data Collection Missions

Conclusion



Lessons learned

- Algorithms that work reliably in simulation encounter RF variability, intermittent connectivity, mobility, timing, and safety constraints during physical testbed experiments
- Testing basic, moderate, and advanced setups isolates failure modes in hybrid truck-drone configurations
- Repeatable runs need parameterized experiment pipelines mapped to AERPAW resources, with the AERPAW team coordination for FCC/FAA/NTIA compliance
- Experiments failed arbitrarily sometimes without configuration changes, requiring AERPAW support to resume the experiment

Potential Next steps

- Scale to the full hybrid topology (LAM6 + SAM4 + rover) with multi-vehicle coordination
- Inject controlled network stress: dead zones, RF congestion, long-range links
- Capture full measurement traces and benchmark meta-heuristic, MILP, and RL planners against each other
- Release testbed scripts and case studies to the AERPAW community



Thank you for your attention!

Questions?



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