Multi-Agent Delivery System Using Drones

Agents and Multi-Agent Systems

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▶ Problem Description

- Warehouses with orders to be delivered using a fleet of drones
- **Multi-agent system** - decentralized, asynchronous, agents with incomplete information
- Drones must be autonomous agents - making **decisions about deliveries**
- Warehouses must be autonomous agents - **allocating orders** to drones
- **Main objective:**
    - getting agents to cooperate in order to optimise delivery times
- Achieve a scalable and efficient solution

▶ System Description

- **Technologies**:
  - **Backend** - Python, Spade, Prosody, Docker
  - **Frontend** - Flask, Leaflet, Javascript
- **Environment:** partially observable, multi agent, deterministic, sequential, static, continuous
- Drones are **available to consider picking orders**:
  - at the starting point - in a warehouse
  - each time they deliver an order:
    - go pick up some more orders to a warehouse if worth it
    - or continue with current tasks
- Warehouses **suggest a couple of orders** to an available drone and wait for its decision
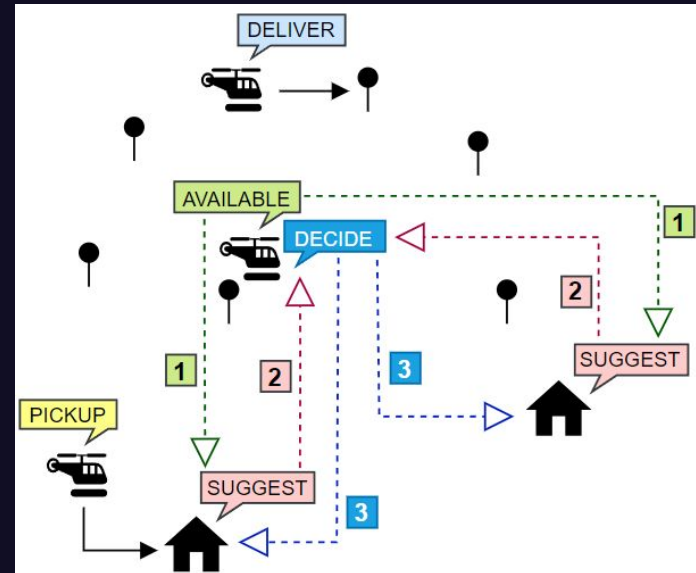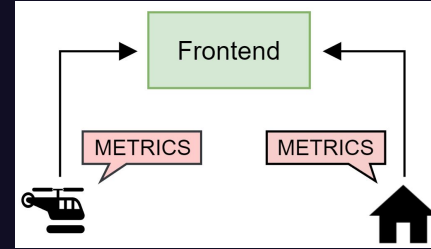
▶ Interactions and Protocols

- Order decision/allocation cooperative process:
  - **many-to-one** negotiation - **ContractNet** protocol
  - bids by warehouse agents and evaluation by drone agents - one-sided auction
- **FIPA performatives** (negotiation) - *propose, accept-proposal, reject-proposal*
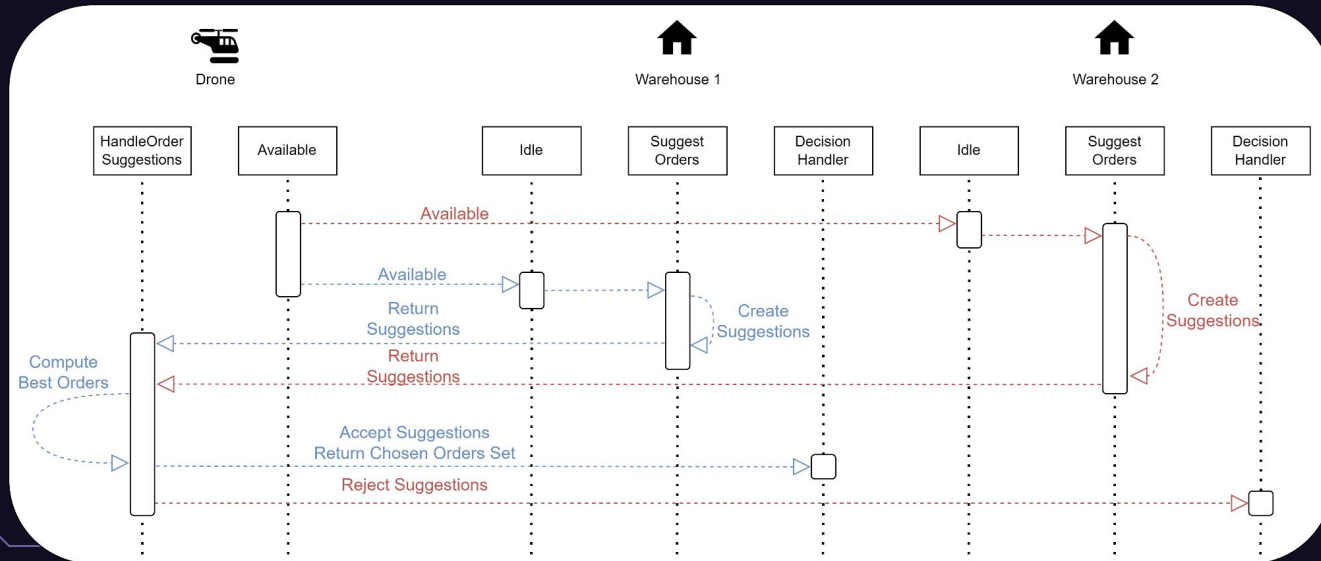
WarehouseAgent - Architecture and Strategies

- **Model-based** agent:
    - maintain internal state of its orders (that haven't been delivered or picked-up)
    - decisions made regarding orders destination and drone's capacity

- **Receives message** from drone and **handles** accordingly:
    - SUGGEST → warehouse expected to return a **proposal** with suggestions - **orders are marked as reserved**
    - DECIDE → drone either accepted or rejected the proposal - **orders not accepted are freed**
    - PICKUP → confirms pickup of the drone orders
    - DISMISS → after warehouse's stock is depleted - every request is refused
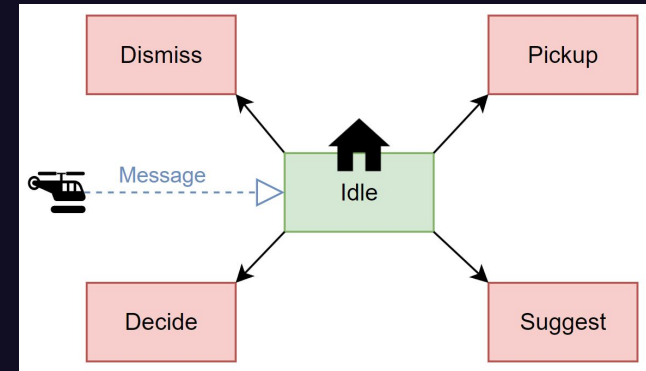
▶ WarehouseAgent - Architecture and Strategies

- Matrix **NxN** to retrieve closer aggregates faster:
  - orders placed by their **coordinates**
  - when making a suggestion - choose orders up to **3** times of drone's available capacity:
    - drone will then decide best order subset from those
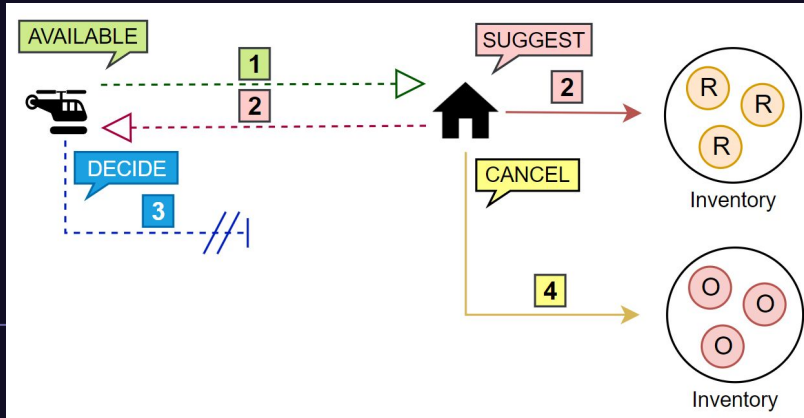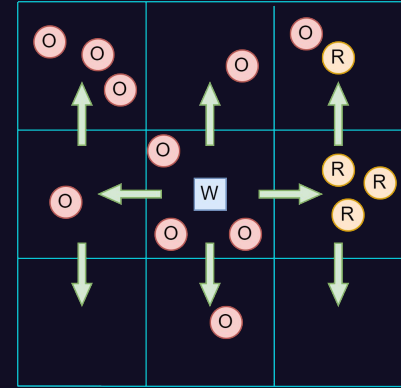
- **Suggested** orders **marked as reserved** to avoid concurrency between drones:
  - after a few seconds **without** receiving a **decision**, orders are freed

▶ DroneAgent - Architecture and Strategies

- **Utility-based** agent:
  - conflicting goals - travel time or distance, capacity level, autonomy
- **Utility** function:
  - measures **order set** that doesn't exceed capacity
  - **maximize capacity** level - avoid travelling with unused capacity
  - **minimize autonomy wastage**:
    - distance of best path (with greedy algorithm)
    - short travel distances - good utility (low consumption)
  - worst utility cases:
    - sets with no orders
    - sets whose total distance exceeds available autonomy
  - **final result** - sum of utility functions

▶ DroneAgent - Architecture and Strategies

- Finite **state machine** (FSM) behaviour:
  - AVAILABLE → informs availability to consider orders from warehouses
  - SUGGEST → [proceed with current orders] vs [go to warehouse with best order set within suggested orders and add to drone] - compare utilities and inform decision (orders chosen)
  - PICKUP → move to warehouse (periodically), recharge and pick up designated orders - figure out furthest order reachable (and closest warehouse there) with autonomy
  - DELIVER → move to next order destination (periodically), deliver and check recharging need
  - DEAD → absence of orders to attend, no battery or error
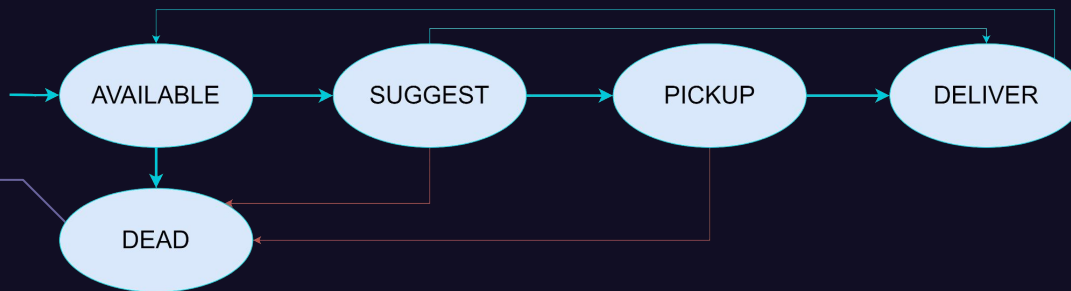
State variables:

- position, velocity, autonomy
- orders to deliver, orders to pick up
- next warehouse

▶ Experiments and Results

	All Strategies Combined	**W/o Warehouse Matrix**	**W/o Drone Utility Function**
TOTAL DELIVERY TIME	25h03m00s	25h59m10s	39h46m00s
AVERAGE DELIVERY TIME	06h15m45s	06h29m47s	09h56m30s
MINIMUM DELIVERY TIME	05h57m30s	06h15m20s	09h42m30s
MAXIMUM DELIVERY TIME	06h27m30s	06h44m40s	10h10m40s
AVERAGE DRONE OCCUPANCY RATES	98.4%	98.1%	95.3%
AVERAGE DRONE ENERGY CONSUMPTION	1127%	1169%	1790%

The approach using all the strategies achieved the best results all around with minimum processing time.

▶ Real-time Interface

▶ Conclusions

- **Multi-agent delivery system** exceeds the expectations:
  - scalable and efficient solution
  - handles the interaction of multiple entities/agents at once
- Main trade-offs to consider:
  - **scalability vs efficiency** - as the system scales, coordination overhead increases
  - **autonomy vs control** - autonomy allows flexibility but control leads to optimal global decisions
  - **utility vs constraints** - function for resource allocation but without compromising drones
  - **real-time adaptation vs predictability** - deal with stock changes without affecting schedules
- **Future work**:
  - investigate new utility and path finder implementations
  - consider some unexpected events in the environment with possible effects on agents

► Annexes

- All Strategies Combined - results (median of 5 runs, running at *500 speed)

Metrics

Total	Drone: drone1	Drone: drone2	Drone: drone3	Drone: drone4
Distance: 1817.58 km	Distance: 454.84 km	Distance: 469.68 km	Distance: 430.52 km	Distance: 462.55 km
Capacity: 0.00 %	Capacity: 0.00 %	Capacity: 0.00 %	Capacity: 0.00 %	Capacity: 0.00 %
Autonomy: 54.10 %	Autonomy: 50.27 %	Autonomy: 50.27 %	Autonomy: 65.57 %	Autonomy: 50.27 %
Orders Delivered: 161	Orders Delivered: 45	Orders Delivered: 41	Orders Delivered: 39	Orders Delivered: 36

Metrics

Total	Drone: drone1	Drone: drone2	Drone: drone3	Drone: drone4
Distance: 1779.35 km	Distance: 466.45 km	Distance: 428.88 km	Distance: 464.48 km	Distance: 419.54 km
Capacity: 0.00 %	Capacity: 0.00 %	Capacity: 0.00 %	Capacity: 0.00 %	Capacity: 0.00 %
Autonomy: 52.18 %	Autonomy: 57.92 %	Autonomy: 50.27 %	Autonomy: 50.27 %	Autonomy: 50.27 %
Orders Delivered: 161	Orders Delivered: 41	Orders Delivered: 43	Orders Delivered: 37	Orders Delivered: 40

Metrics

Total	Drone: drone1	Drone: drone2	Drone: drone3	Drone: drone4
Distance: 1795.50 km	Distance: 467.16 km	Distance: 446.69 km	Distance: 461.45 km	Distance: 420.20 km
Capacity: 0.00 %	Capacity: 0.00 %	Capacity: 0.00 %	Capacity: 0.00 %	Capacity: 0.00 %
Autonomy: 52.18 %	Autonomy: 50.27 %	Autonomy: 57.92 %	Autonomy: 50.27 %	Autonomy: 50.27 %
Orders Delivered: 161	Orders Delivered: 41	Orders Delivered: 38	Orders Delivered: 38	Orders Delivered: 44

Metrics

Total	Drone: drone1	Drone: drone2	Drone: drone3	Drone: drone4
Distance: 1788.90 km	Distance: 458.44 km	Distance: 460.45 km	Distance: 434.32 km	Distance: 435.70 km
Capacity: 0.00 %	Capacity: 0.00 %	Capacity: 0.00 %	Capacity: 0.00 %	Capacity: 0.00 %
Autonomy: 52.18 %	Autonomy: 50.27 %	Autonomy: 50.27 %	Autonomy: 50.27 %	Autonomy: 57.92 %
Orders Delivered: 161	Orders Delivered: 46	Orders Delivered: 39	Orders Delivered: 36	Orders Delivered: 40

Metrics

Total	Drone: drone1	Drone: drone2	Drone: drone3	Drone: drone4
Distance: 1822.13 km	Distance: 440.93 km	Distance: 460.08 km	Distance: 460.58 km	Distance: 460.54 km
Capacity: 0.00 %	Capacity: 0.00 %	Capacity: 0.00 %	Capacity: 0.00 %	Capacity: 0.00 %
Autonomy: 54.10 %	Autonomy: 65.57 %	Autonomy: 50.27 %	Autonomy: 50.27 %	Autonomy: 50.27 %
Orders Delivered: 161	Orders Delivered: 45	Orders Delivered: 44	Orders Delivered: 35	Orders Delivered: 37

▶ Annexes

- W/o Warehouse Matrix - results (median of 5 runs, running at *500 speed)

Metrics

Total	**Drone:** drone1	**Drone:** drone2	**Drone:** drone3	**Drone:** drone4
Distance: 1936.16 km	**Distance:** 519.11 km	**Distance:** 493.57 km	**Distance:** 462.85 km	**Distance:** 460.62 km
Capacity: 0.00 %	**Capacity:** 0.00 %	**Capacity:** 0.00 %	**Capacity:** 0.00 %	**Capacity:** 0.00 %
Autonomy: 50.27 %	**Autonomy:** 50.27 %	**Autonomy:** 50.27 %	**Autonomy:** 50.27 %	**Autonomy:** 50.27 %
Orders Delivered: 161	**Orders Delivered:** 43	**Orders Delivered:** 42	**Orders Delivered:** 45	**Orders Delivered:** 31

Metrics

Total	**Drone:** drone1	**Drone:** drone2	**Drone:** drone3	**Drone:** drone4
Distance: 1823.73 km	**Distance:** 460.99 km	**Distance:** 458.23 km	**Distance:** 463.27 km	**Distance:** 441.24 km
Capacity: 0.00 %	**Capacity:** 0.00 %	**Capacity:** 0.00 %	**Capacity:** 0.00 %	**Capacity:** 0.00 %
Autonomy: 50.27 %	**Autonomy:** 50.27 %	**Autonomy:** 50.27 %	**Autonomy:** 50.27 %	**Autonomy:** 50.27 %
Orders Delivered: 161	**Orders Delivered:** 41	**Orders Delivered:** 40	**Orders Delivered:** 42	**Orders Delivered:** 38

Metrics

Total	**Drone:** drone1	**Drone:** drone2	**Drone:** drone3	**Drone:** drone4
Distance: 1914.77 km	**Distance:** 486.16 km	**Distance:** 474.60 km	**Distance:** 480.83 km	**Distance:** 473.18 km
Capacity: 0.00 %	**Capacity:** 0.00 %	**Capacity:** 0.00 %	**Capacity:** 0.00 %	**Capacity:** 0.00 %
Autonomy: 52.68 %	**Autonomy:** 50.27 %	**Autonomy:** 50.27 %	**Autonomy:** 59.92 %	**Autonomy:** 50.27 %
Orders Delivered: 161	**Orders Delivered:** 39	**Orders Delivered:** 44	**Orders Delivered:** 39	**Orders Delivered:** 39

Metrics

Total	**Drone:** drone1	**Drone:** drone2	**Drone:** drone3	**Drone:** drone4
Distance: 1874.13 km	**Distance:** 468.55 km	**Distance:** 484.57 km	**Distance:** 447.33 km	**Distance:** 473.68 km
Capacity: 0.00 %	**Capacity:** 0.00 %	**Capacity:** 0.00 %	**Capacity:** 0.00 %	**Capacity:** 0.00 %
Autonomy: 52.68 %	**Autonomy:** 50.27 %	**Autonomy:** 59.92 %	**Autonomy:** 50.27 %	**Autonomy:** 50.27 %
Orders Delivered: 161	**Orders Delivered:** 42	**Orders Delivered:** 41	**Orders Delivered:** 45	**Orders Delivered:** 33

Metrics

Total	**Drone:** drone1	**Drone:** drone2	**Drone:** drone3	**Drone:** drone4
Distance: 1808.12 km	**Distance:** 454.45 km	**Distance:** 476.31 km	**Distance:** 431.12 km	**Distance:** 446.24 km
Capacity: 0.00 %	**Capacity:** 0.00 %	**Capacity:** 0.00 %	**Capacity:** 0.00 %	**Capacity:** 0.00 %
Autonomy: 50.27 %	**Autonomy:** 50.27 %	**Autonomy:** 50.27 %	**Autonomy:** 50.27 %	**Autonomy:** 50.27 %
Orders Delivered: 161	**Orders Delivered:** 45	**Orders Delivered:** 43	**Orders Delivered:** 39	**Orders Delivered:** 34

▶ Annexes

- W/o Drone Utility Function - results (median of 5 runs, running at *500 speed)

Metrics

Total	Drone: drone1	Drone: drone2	Drone: drone3	Drone: drone4
Distance: 2853.59 km	Distance: 730.63 km	Distance: 725.33 km	Distance: 713.57 km	Distance: 684.06 km
Capacity: 0.00 %	Capacity: 0.00 %	Capacity: 0.00 %	Capacity: 0.00 %	Capacity: 0.00 %
Autonomy: 50.27 %	Autonomy: 50.27 %	Autonomy: 50.27 %	Autonomy: 50.27 %	Autonomy: 50.27 %
Orders Delivered: 161	Orders Delivered: 41	Orders Delivered: 40	Orders Delivered: 43	Orders Delivered: 37

Metrics

Total	Drone: drone1	Drone: drone2	Drone: drone3	Drone: drone4
Distance: 2868.01 km	Distance: 728.40 km	Distance: 737.56 km	Distance: 711.73 km	Distance: 690.33 km
Capacity: 0.00 %	Capacity: 0.00 %	Capacity: 0.00 %	Capacity: 0.00 %	Capacity: 0.00 %
Autonomy: 50.27 %	Autonomy: 50.27 %	Autonomy: 50.27 %	Autonomy: 50.27 %	Autonomy: 50.27 %
Orders Delivered: 161	Orders Delivered: 41	Orders Delivered: 41	Orders Delivered: 40	Orders Delivered: 39

Metrics

Total	Drone: drone1	Drone: drone2	Drone: drone3	Drone: drone4
Distance: 2835.52 km	Distance: 728.77 km	Distance: 705.02 km	Distance: 702.83 km	Distance: 698.90 km
Capacity: 0.00 %	Capacity: 0.00 %	Capacity: 0.00 %	Capacity: 0.00 %	Capacity: 0.00 %
Autonomy: 59.92 %	Autonomy: 59.92 %	Autonomy: 59.92 %	Autonomy: 59.92 %	Autonomy: 59.92 %
Orders Delivered: 161	Orders Delivered: 42	Orders Delivered: 41	Orders Delivered: 40	Orders Delivered: 38

Metrics

Total	Drone: drone1	Drone: drone2	Drone: drone3	Drone: drone4
Distance: 2902.14 km	Distance: 716.13 km	Distance: 741.42 km	Distance: 726.78 km	Distance: 717.81 km
Capacity: 0.00 %	Capacity: 0.00 %	Capacity: 0.00 %	Capacity: 0.00 %	Capacity: 0.00 %
Autonomy: 50.27 %	Autonomy: 50.27 %	Autonomy: 50.27 %	Autonomy: 50.27 %	Autonomy: 50.27 %
Orders Delivered: 161	Orders Delivered: 40	Orders Delivered: 40	Orders Delivered: 41	Orders Delivered: 40

Metrics

Total	Drone: drone1	Drone: drone2	Drone: drone3	Drone: drone4
Distance: 2858.29 km	Distance: 707.50 km	Distance: 710.10 km	Distance: 711.82 km	Distance: 728.87 km
Capacity: 0.00 %	Capacity: 0.00 %	Capacity: 0.00 %	Capacity: 0.00 %	Capacity: 0.00 %
Autonomy: 57.51 %	Autonomy: 50.27 %	Autonomy: 59.92 %	Autonomy: 59.92 %	Autonomy: 59.92 %
Orders Delivered: 161	Orders Delivered: 41	Orders Delivered: 41	Orders Delivered: 38	Orders Delivered: 41