# Collaborative Multi-UAV Data Fusion for SAR Applications with Moving Targets


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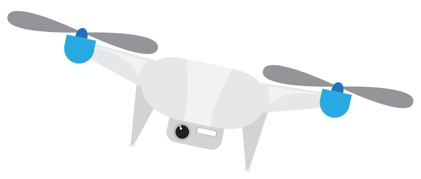


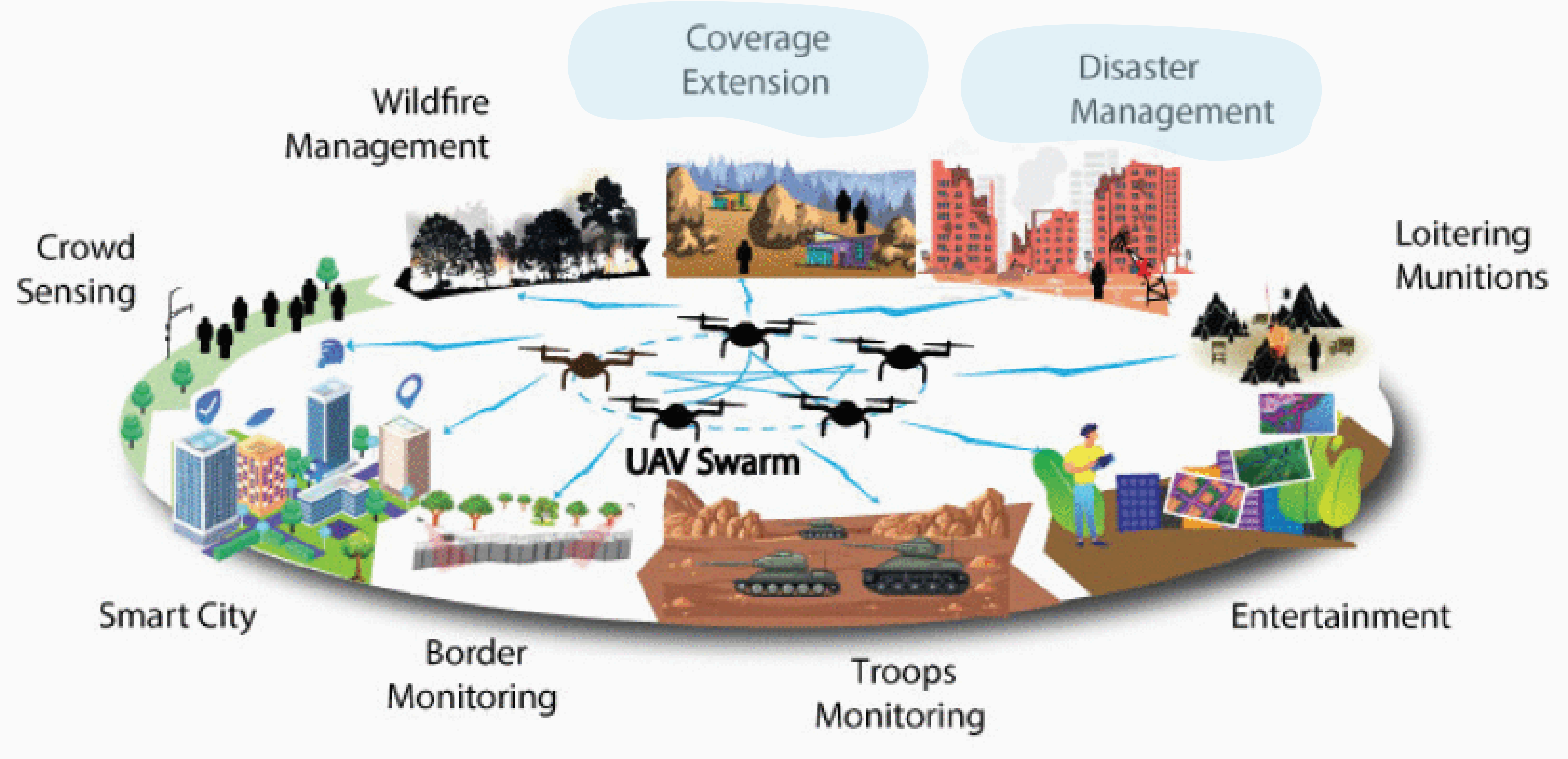

**LAC** Laboratory for Advanced Collaboration
**DI** Department of Informatics
**PUC-Rio** Pontificial Catholic University of Rio de Janeiro

# Project GrADyS

https://bit.ly/gradys

# UAVs in Dynamic Environments

- UAVs communicate in a distributed manner.
- Decisions are made based on information gathered from the environment and neighboring UAVs.
- Integration of several subsystems, including:
  - Trajectory planning
  - Localization
  - Task coordination




*source: Javed et al. State-of-the-Art and Future Research Challenges in UAV SwarmsIEEE Internet of Things Journal. 2024.*

# Search and Rescue (SAR)

source: E. T. Alotaibi, S. S. Alqefari and A. Koubaa, "LSAR: Multi-UAV Collaboration for Search and Rescue Missions," in IEEE Access, vol. 7, pp. 55817-55832, 2019

## Main goals

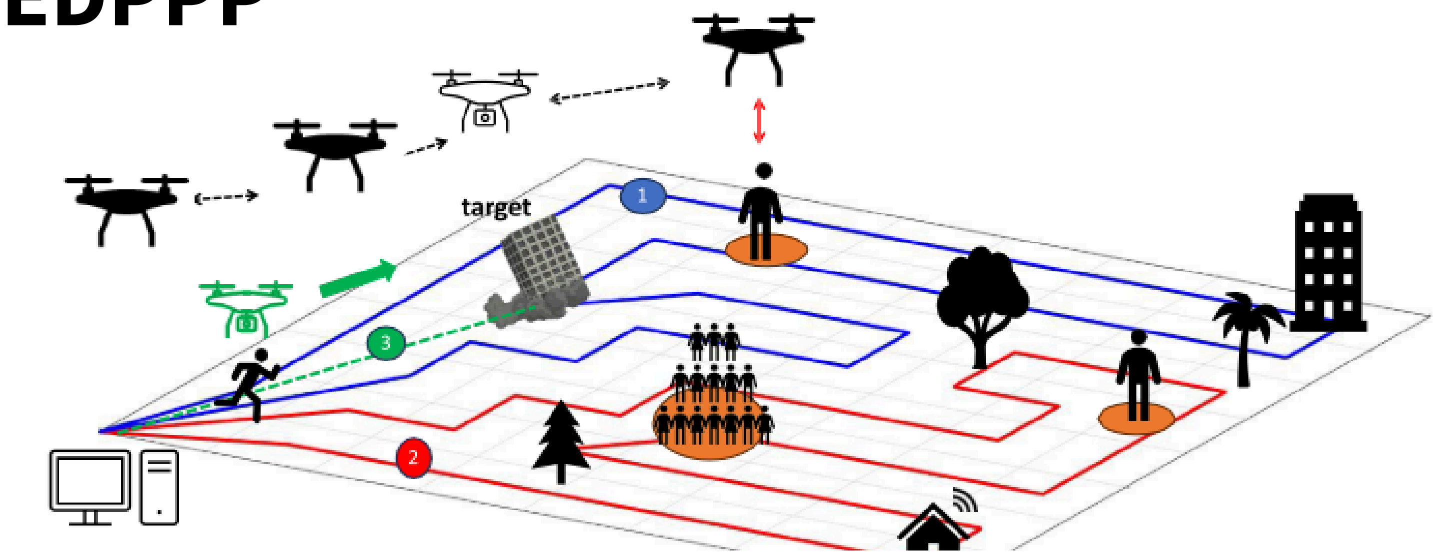
- **Identifying** stationary or mobile **targets** in the **shortest time** possible, even those once deemed challenging or impossible for humans to achieve.

## Challanges

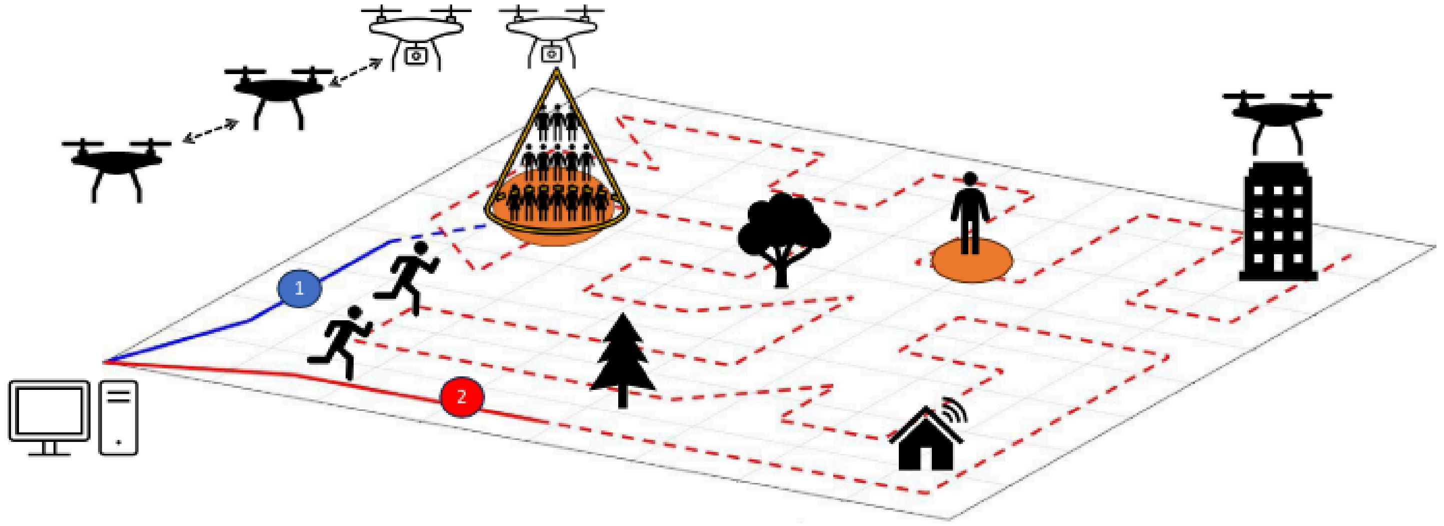
- Expansive search area
- Unknown target locations
- Time constraints

# Multiple UAVs for SAR operations with Stationary Targets

**EDPPP**




**DAPP**



***DYNAMIC MULTI-UAV PATH PLANNING FOR MULTI-TARGET SEARCH AND CONNECTIVITY***

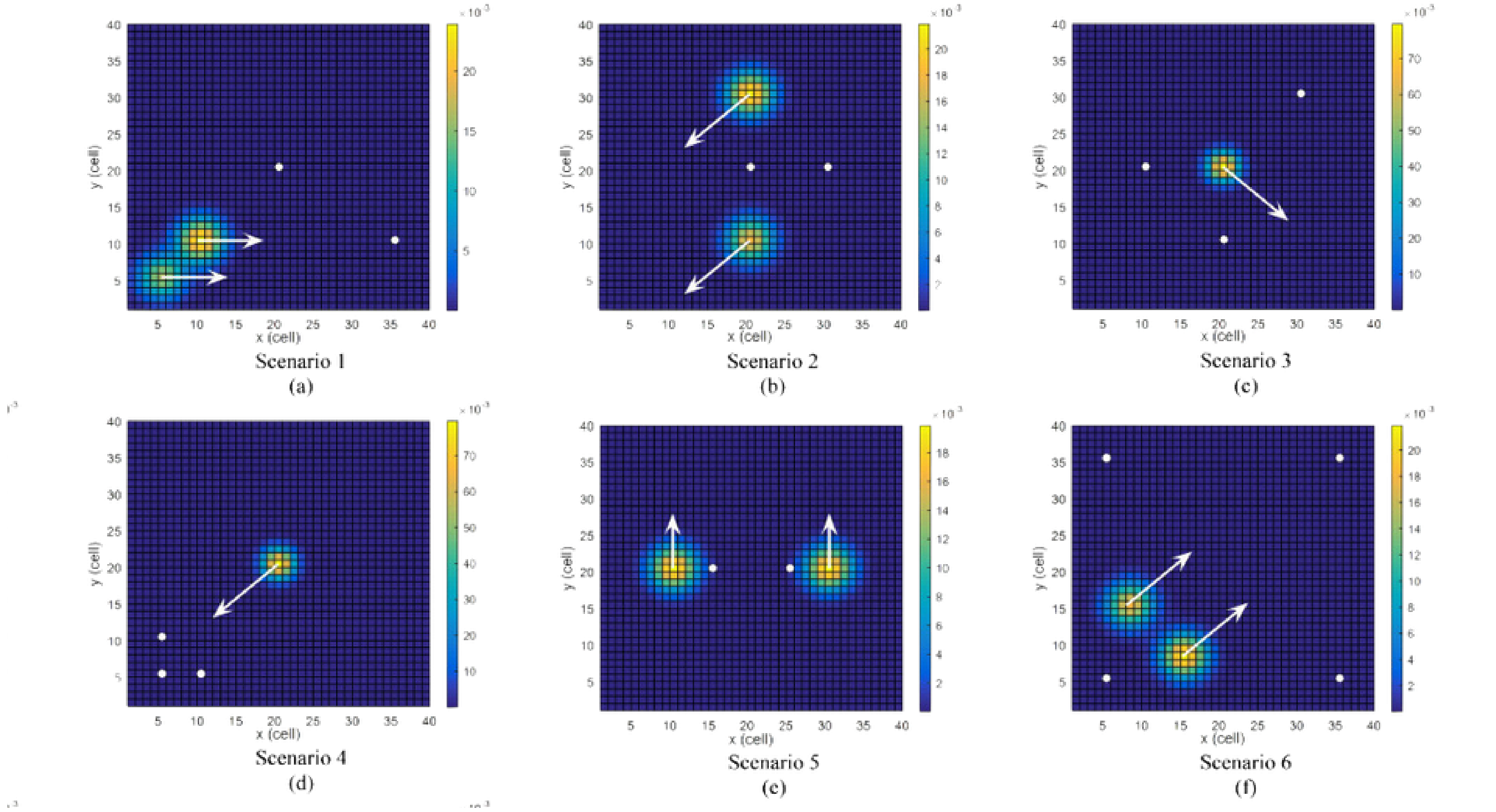
***DOI:*** *HTTP://DOI.ORG/10.1109/TVT.2024.3363840*

**Yanmaz et. al. (2024)** models the search path problem as a ***Multiple Traveling Salesman Problem (mTSP)*** and use a ***genetic algorithm***-based solution. This approach connect and monitor multiple randomly distributed targets to the ground control station (GCS) while maintaining the connectivity of the UAVs to GCS.

- ***Extended Detection Priority Path Planning (EDPPP)***
  - follow pre-planned paths and inject new UAVs to monitor the detected targets
- ***Detection Adaptive Path Planning (DAPP)***
  - assign a search UAV to monitor target, and re-plan remaining UAV paths

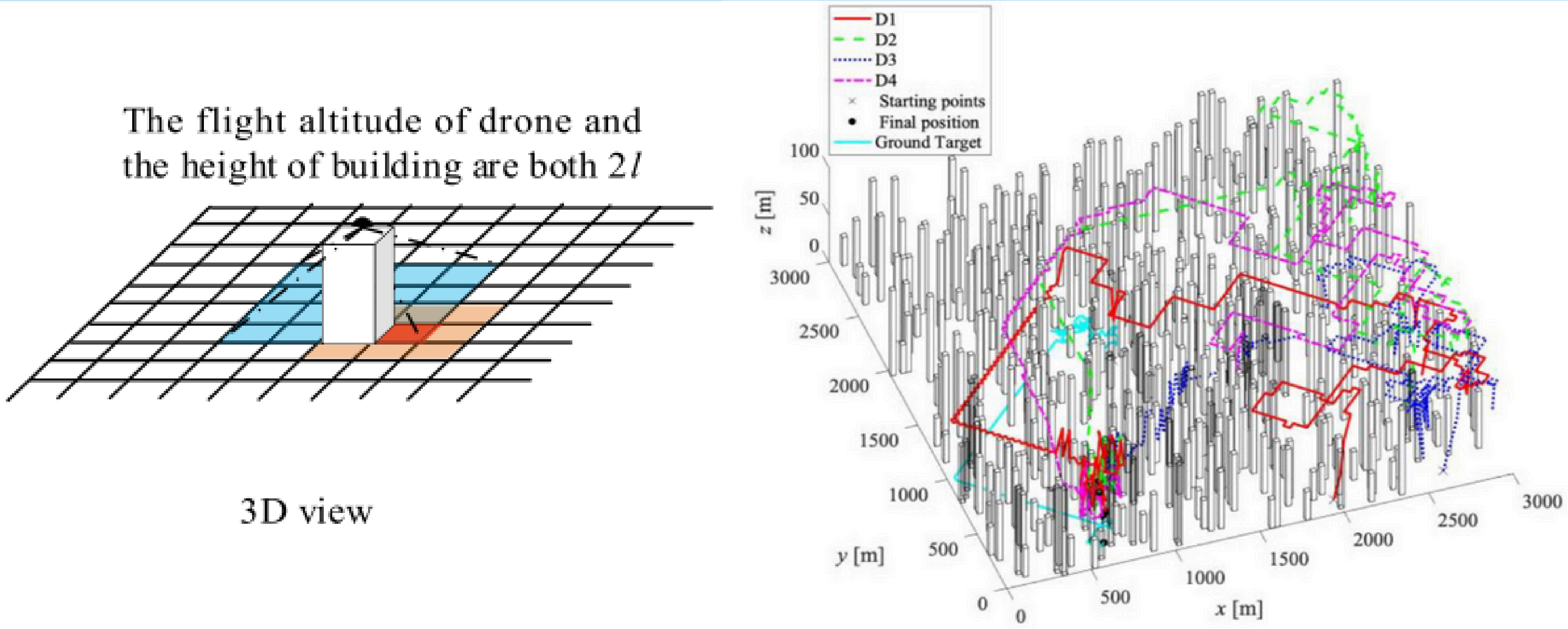
# Multiple UAVs for SAR operations with Mobile Targets

**Alanezi et al. (2022)** propose a method for searching dynamic targets using multiple coordinated UAVs and a ***motion-encoded genetic algorithm (MEGA-MP)*** to identify ***areas with a higher probability of containing targets***.




***DYNAMIC TARGET SEARCH USING MULTI-UAVS BASED ON MOTION-ENCODED GENETIC ALGORITHM WITH MULTIPLE PARENTS***

***DOI:*** *HTTP://DOI.ORG/10.1109/ACCESS.2022.3190395*




**Wu et al. (2022)** developed a ***Swarm-Based Imitative Learning Optimization (SBILO)*** algorithm to determine drone waypoints using ***Biogeography-Based Optimization (BSO)*** and ***Teaching-Learning-Based Optimization (TLBO)***. This approach ensures that all drones remain within communication range of at least one other drone to share their target position and formation for effective ***target locking (SAL)***.

***ROUTE COORDINATION OF UAV FLEET TO TRACK A GROUND MOVING TARGET IN SEARCH AND LOCK (SAL) TASK OVER URBAN AIRSPACE***

***DOI:*** *HTTP://DOI.ORG/10.1109/JIOT.2022.3178089*

# Proposed Approach

**Multiple UAV in a Dynamic search Environment(MUDE)**

Method for **searching, detecting, and collecting information** from **mobile targets** within a designated area using swarms of UAVs and a **distributed coordination** algorithm to efficiently cover an **expansive search area** within strict, predefined **time constraints**.

- Multi-sensor fusion and multi-UAV approach for the search of multiple unknown targets in dynamic environments;
- Algorithm for collaboratively planning and adapting UAV paths to navigate routes that maximize the probability of locating targets.

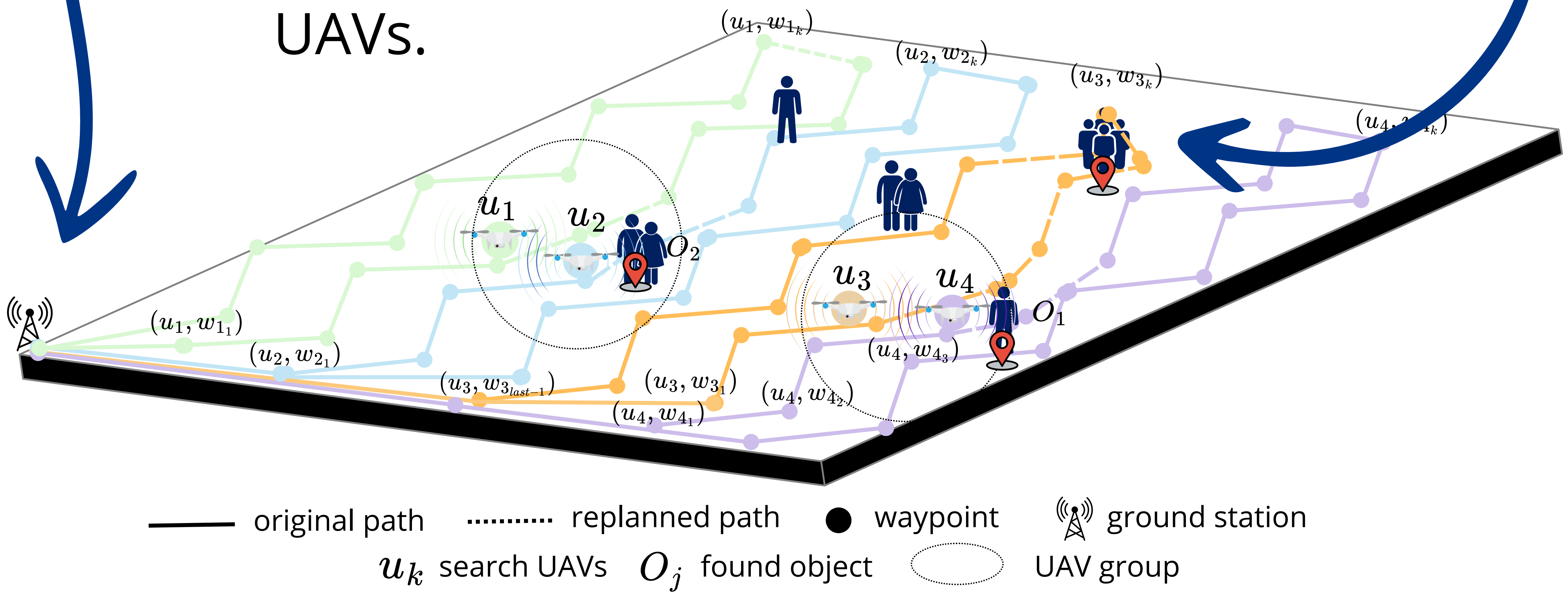
# MUDE: Overview

## Ground station

- Serves as a launch site for UAVs;
- Transmits mission configuration information to the UAVs;
- Receives and stores data collected by the UAVs.

## Targets

- Moving objects that are being searched for in the mission.
- Predictable movement pattern:
  - Targets are often organized into groups and tend to move together.

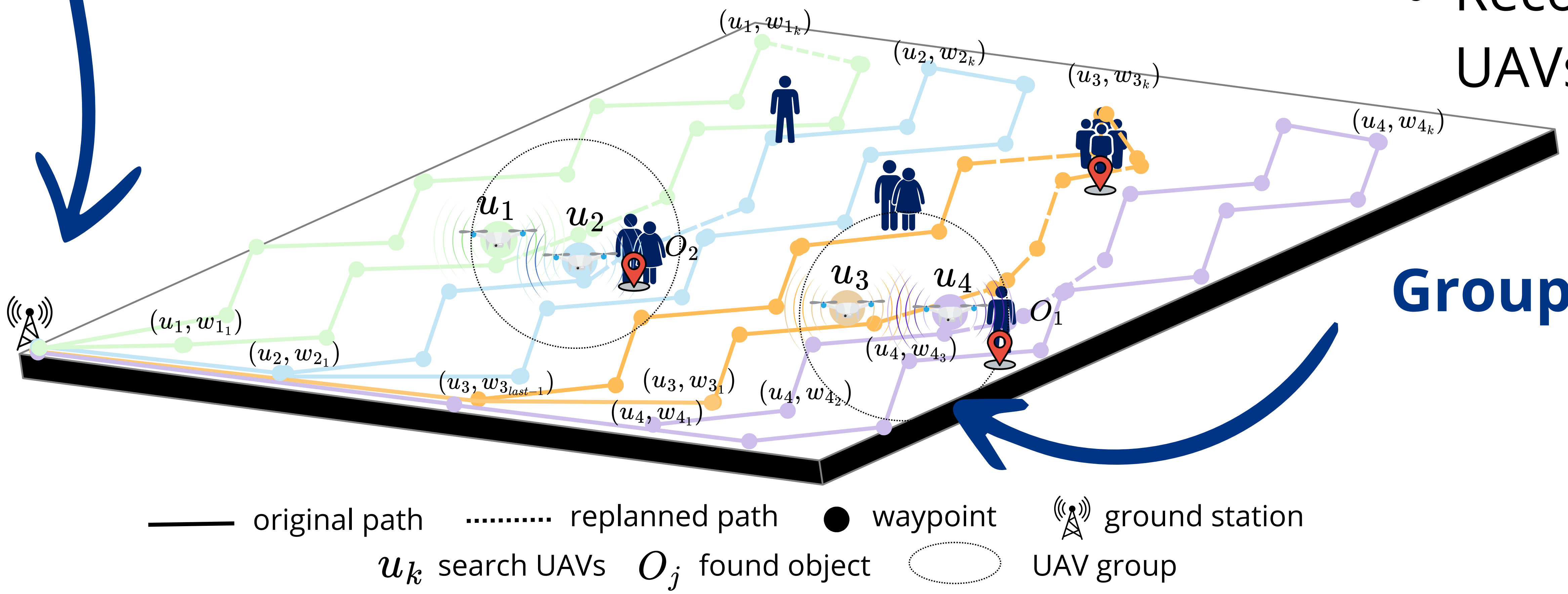


# MUDE: Overview

## Search UAVs

- Identify targets using a sensor located at the center, covering a square area with centrosymmetric projection;
- Can detect targets while flying above;

- UAVs utilize local and decentralized processing to facilitate decision-making;
- Adjusts individual path according to the likelihood of encountering new targets.
- Record and transmit data to other UAVs within their communication



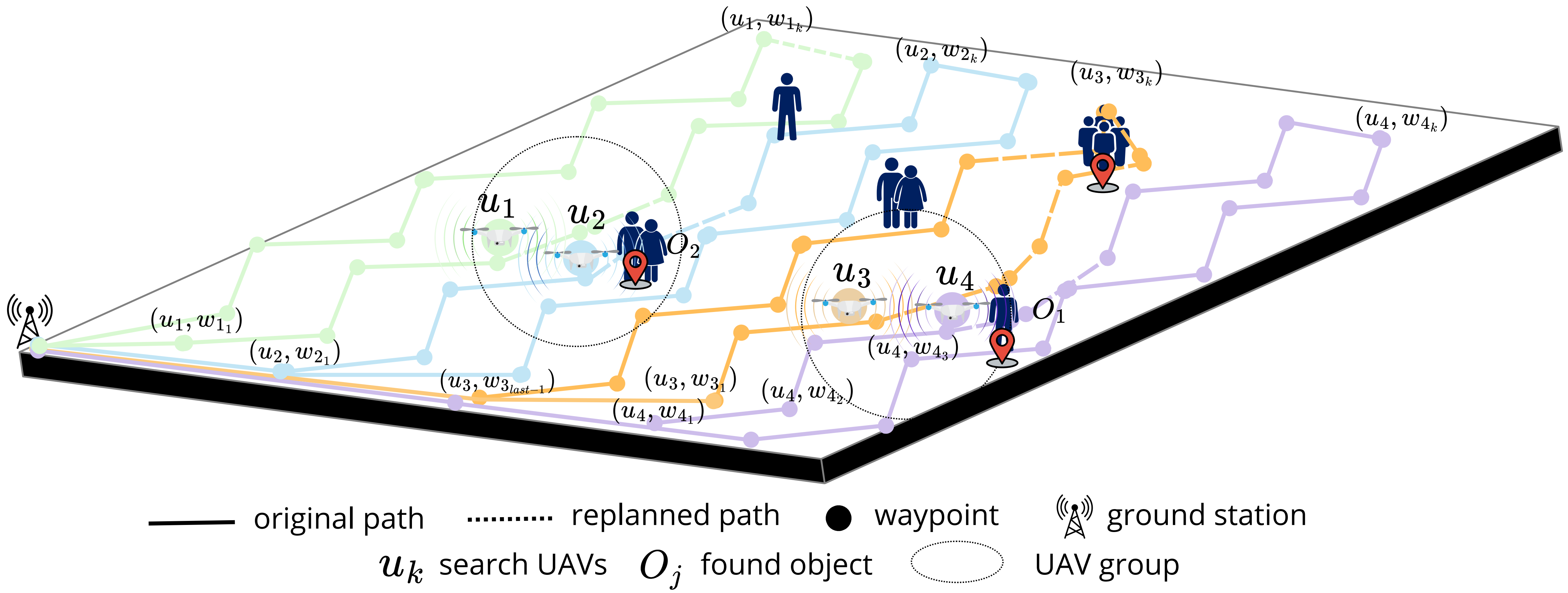

## Group $g_s$

- Information is exchanged by UAVs through direct or indirect communication;
- Group distributed decision to calculate the social path.

# MUDE: Overview

## Mission Inputs

- **A** : search area
- **N** : number of search UAVs
- **T** : maximum duration of the mission
- $\mathbf{W_i}$ : initial individual path for each uav $u_i$
- $\mathbf{r_c}$ : inter-UAV RF communication range
- $\mathbf{v_i}$ : UAVs speed
- **h** : expected UAV flight altitude
- **U** : set of UAVs



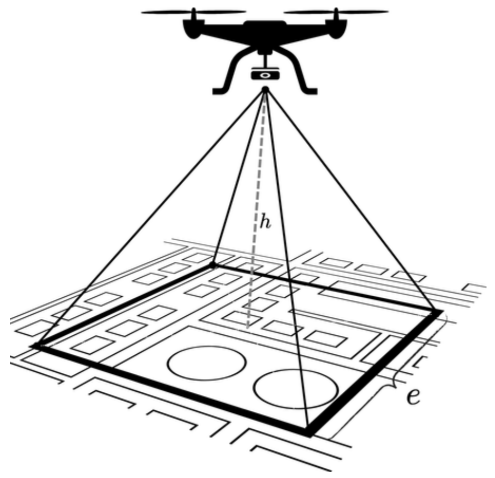

## Mission Outputs

- **k'** : number of found targets
- **TP** : list of found targets
- $\mathbf{T_c}$ : convergence speed

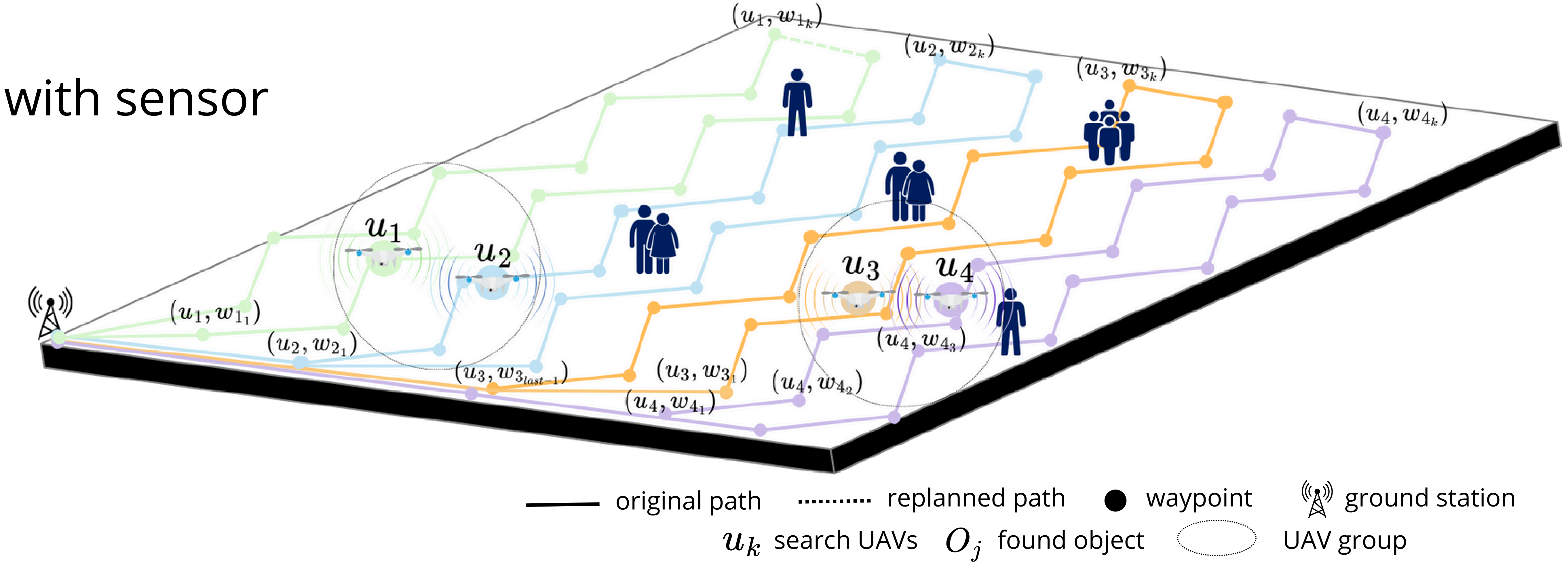
# MUDE: Algorithm

**Search for targets phase**

- Each UAV $u_i$ follows a predefined individual path ( $W_i$ ) that is generated by the ground station.
- Path generated using a Coverage Path Planning (CPP) algorithm.
- Scans the flying area with sensor




$$S_{ground} = 4h^2(\sigma^2 - 1)$$



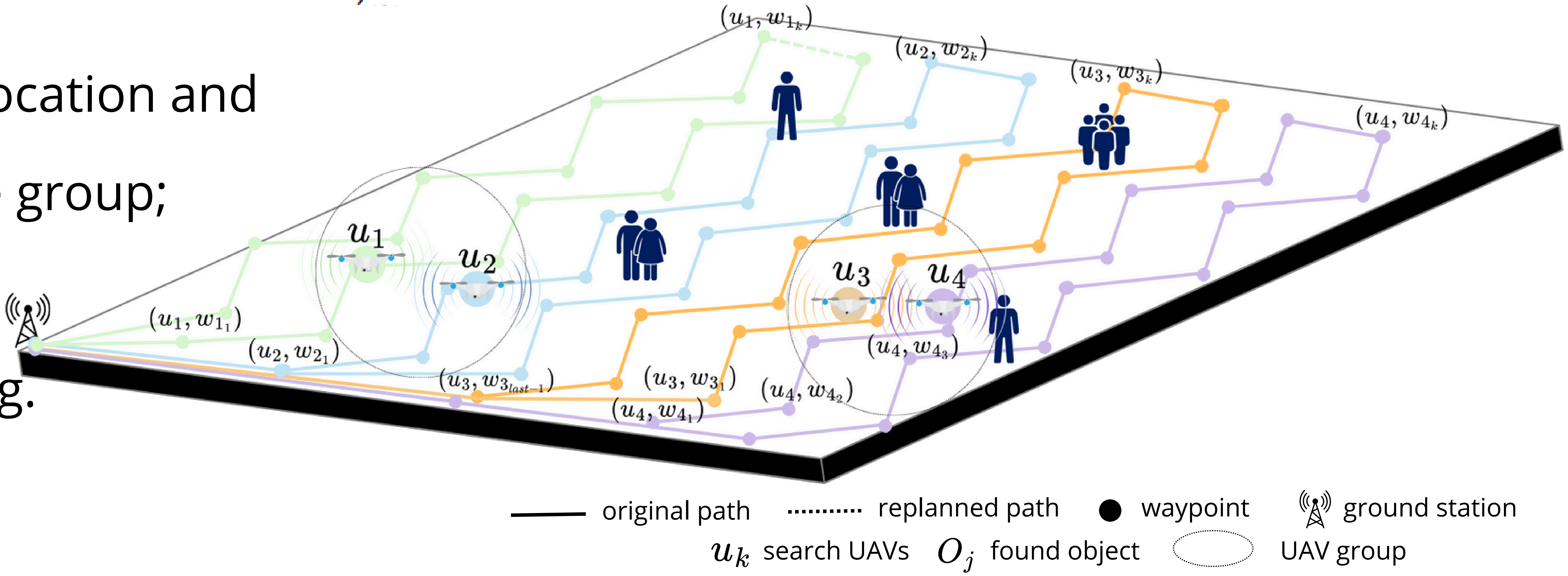
# MUDE: Algorithm

## Search for targets phase - Target detection

- Updates its probability map ($M_i$) using discretized Gaussian distribution;

$$f(x,y) = \frac{1}{2\pi|\Sigma|^{1/2}} \exp\left(-\frac{1}{2}\begin{bmatrix} x-\mu_x \\ y-\mu_y \end{bmatrix}^T \Sigma^{-1} \begin{bmatrix} x-\mu_x \\ y-\mu_y \end{bmatrix}\right)$$

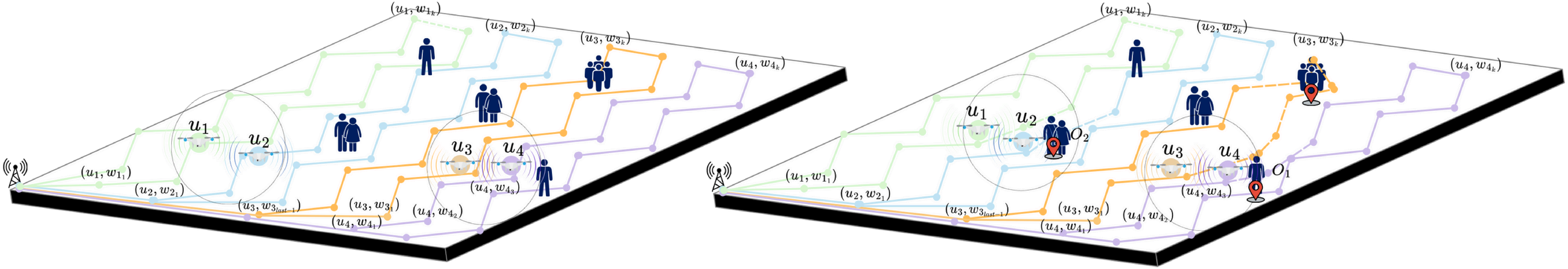
- Broadcast the target location and the updated $M_i$ to the group;
- Start Individual and Social path re-planning.



# MUDE: Algorithm

## (re)Plan Individual Path phase

- Calculates the highest probability coordination $P_{ih}$ to find new target using $M_{i.}$
- Insert and change next waypoints to reach $P_{ih.}$

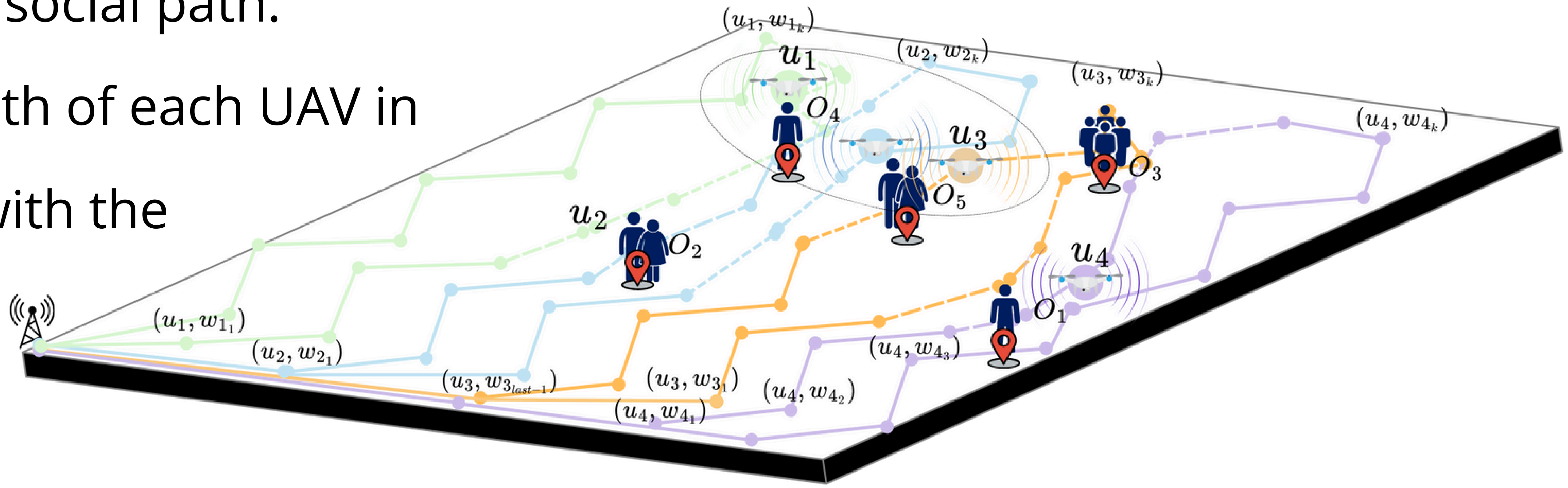


original path · replanned path · waypoint · ground station · $u_k$ search UAVs · $O_j$ found object · UAV group

# MUDE: Algorithm

**(re)Plan Social Path Path phase**

- Using Fast Paxos Consensus Algorithm and the merge of $M_i$ for each $u_i$ in g:
- The group determines the social path.
- Adjusting the individual path of each UAV in the group to target areas with the highest probabilities.
- Identify the coordinates that other UAVs should avoid.
- Groups can be merged or split during a mission.



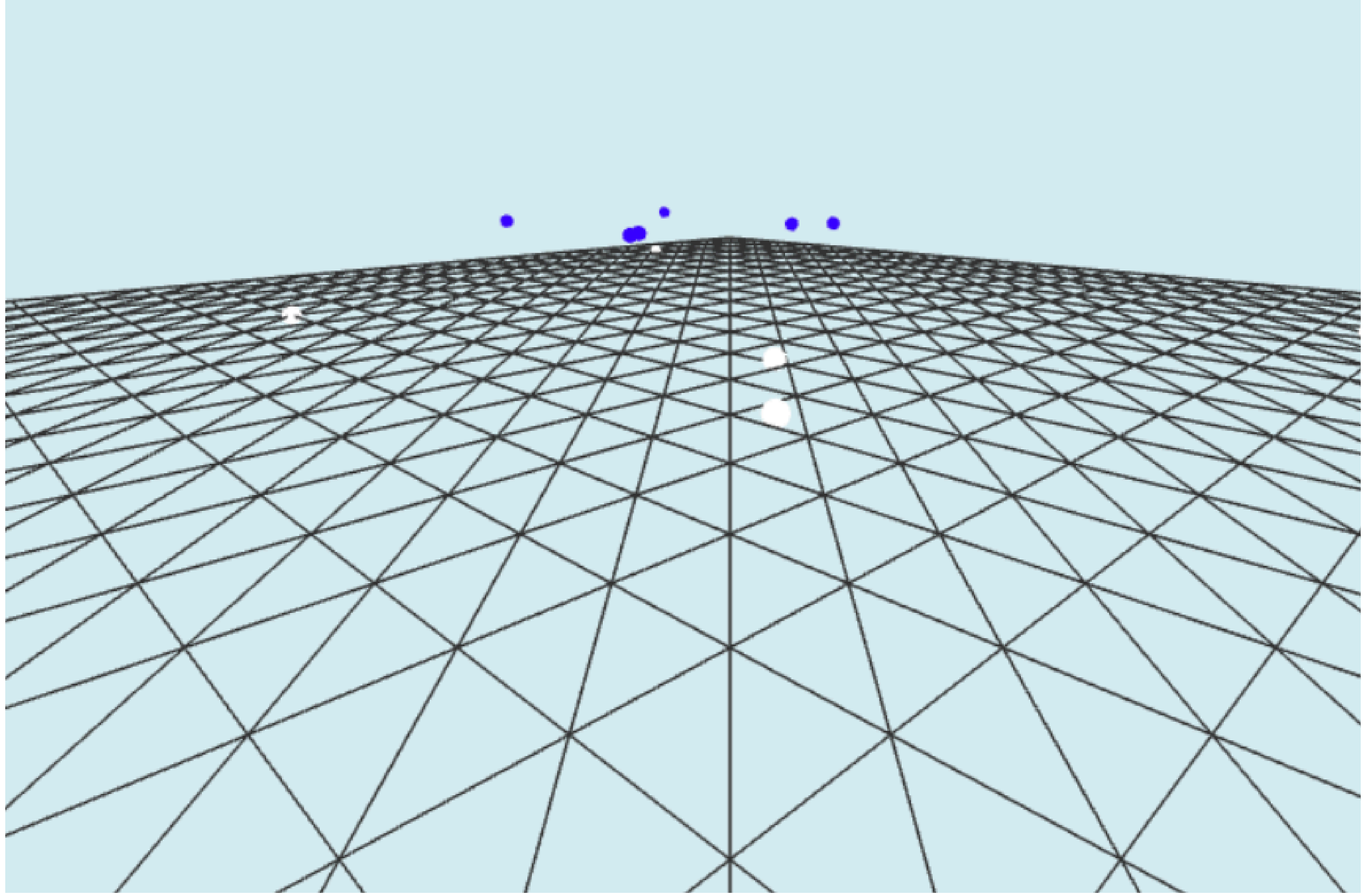
# Experiments: Overview

**Objective**

- Analyze the effectiveness of the approach.
- To analyze the influence of the search area, the number of UAVs on the mission, the targets, and the concentration in the algorithm's assertiveness and flight time.

**Simulator**

- GrADyS-SIM NextGen



# Experiments: Architecture

## Mission and Environment Scenarios:

| Parameter | Range |
|---|---|
| **Area (A):** | 16,36,64 ha |
| **Number of UAV (N):** | 2,4,8,16,64 |
| **Mission Duration (T):** | 900, 1200, 1800 s |
| **Number of Targets (k):** | 2,8,16,50,100 |
| **Targets Clusterization (c):** | 1, 5, 10 groups |
| **Transmission range (rc):** | 20 meters |
| **UAV flight heigh (h):** | 20 meters |
| **Coverage Path Planning** | LMAT |

648 different scenarios

15x executed

## Metrics

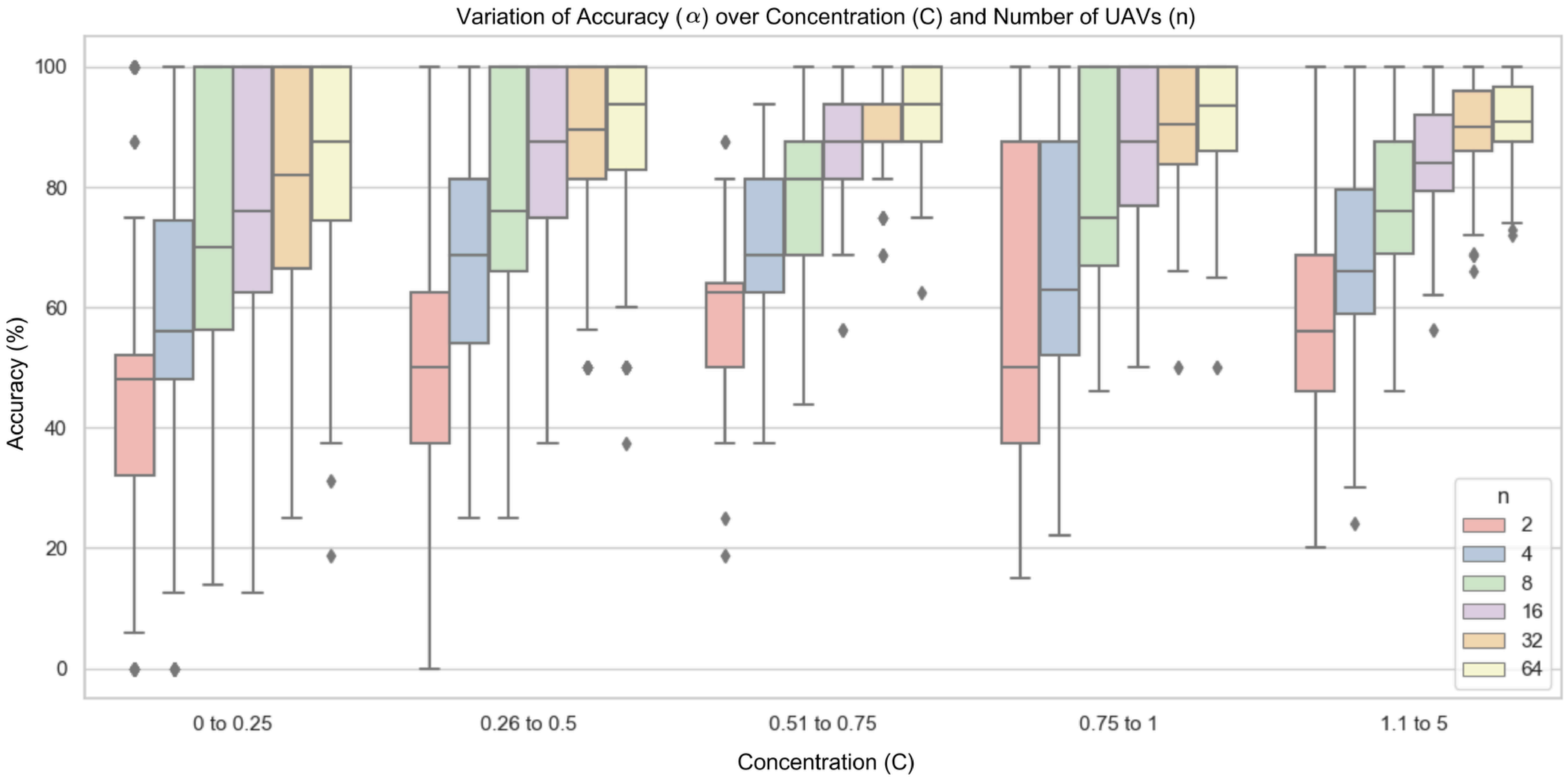
- Accuracy

$$\alpha = \frac{k'}{k}$$

- Concentration target rate

$$C = \frac{g}{d_{\text{cluster}} * l^2}\left(1 - \frac{g-1}{k-1}\right)$$

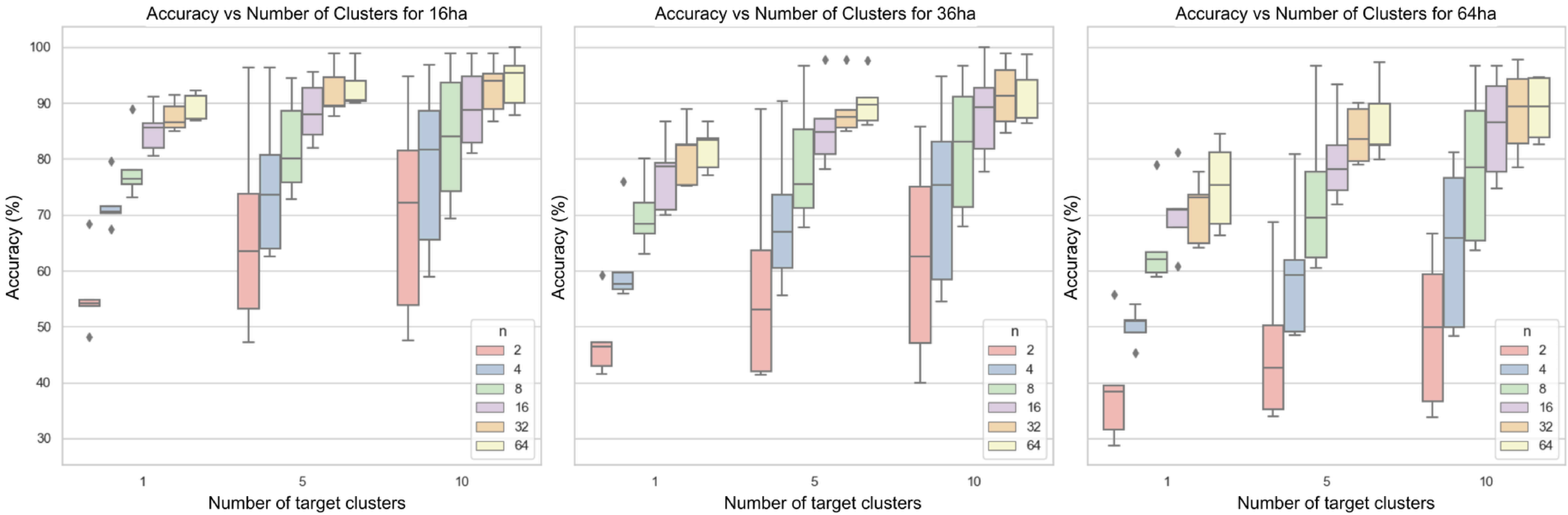
# Results: Accuracy




- **Accuracy increases** with the number of **UAV**
  - plateau with 16 UAVs
  - accuracy >= 90%
- For n=2
  - Very **low accuracy**
  - Insufficient time to cover a **minimum area**

# Results: Clustering

- C ≥ 0.26:
  - accuracy remains relatively constant
- C < 0.26:
  - unstable accuracy




**The performance of the algorithm is more significantly affected by the number of UAVs involved in the mission than by the concentration rate.**

# Conclusions

- **Real-time** and **distributed decision-making** for target identification.
- Average **accuracy rate of 90%**, for $n \geq 16$ and $C > 0.25$
- In environments with **higher target concentrations**, there is an **optimal UAV swarm size**, beyond which operational **efficiency remains stable**.
- The **performance of the algorithm** is influenced more by the **number of UAVs** involved in the mission than by the **concentration rate.**
- The algorithm can **efficiently scale** to handle large numbers of targets within a wide search area.

# Future Work

Comparation with other SARs approach for both stationary and mobile targets.

UAV swarm collaboration with no predetermined route

Support for scenarios where targets exhibit unpredictable movement patterns

Real world experiments

# Thank you!

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GrADyS Simulator
*bit.ly/gradys-sim-nextgen*