Robot and Drone Swarms summary

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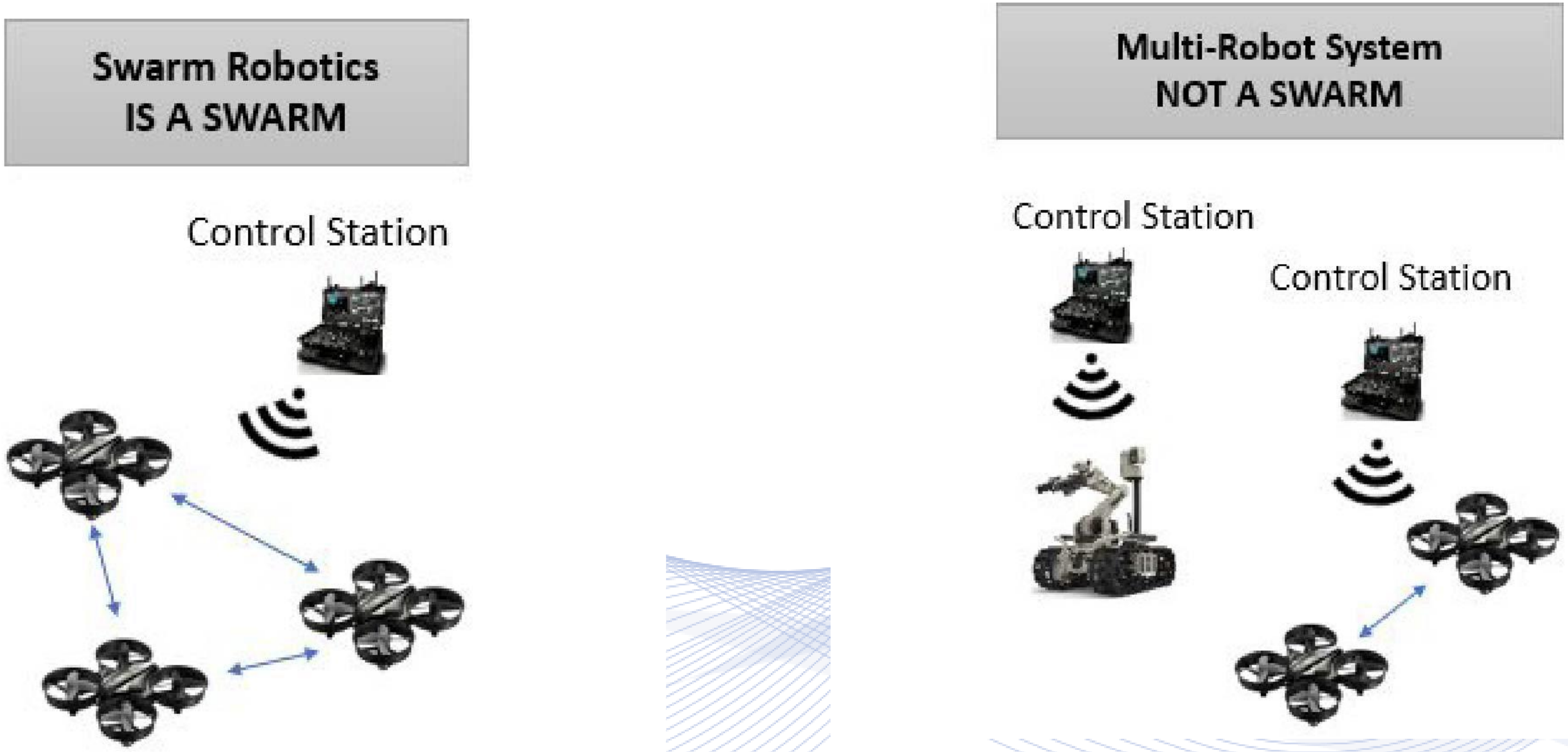
Information Analysis Lab

Robot and Drone Swarms

- **Definition and Applications**
- Communications
- Architecture and Formation
- Mission Planning
- Algorithms
  - Ant Colony Optimization
  - PSO
- Simulators and metrics

Definition and Principles



Drone swarm definition(from [1]).

Goals and Applications

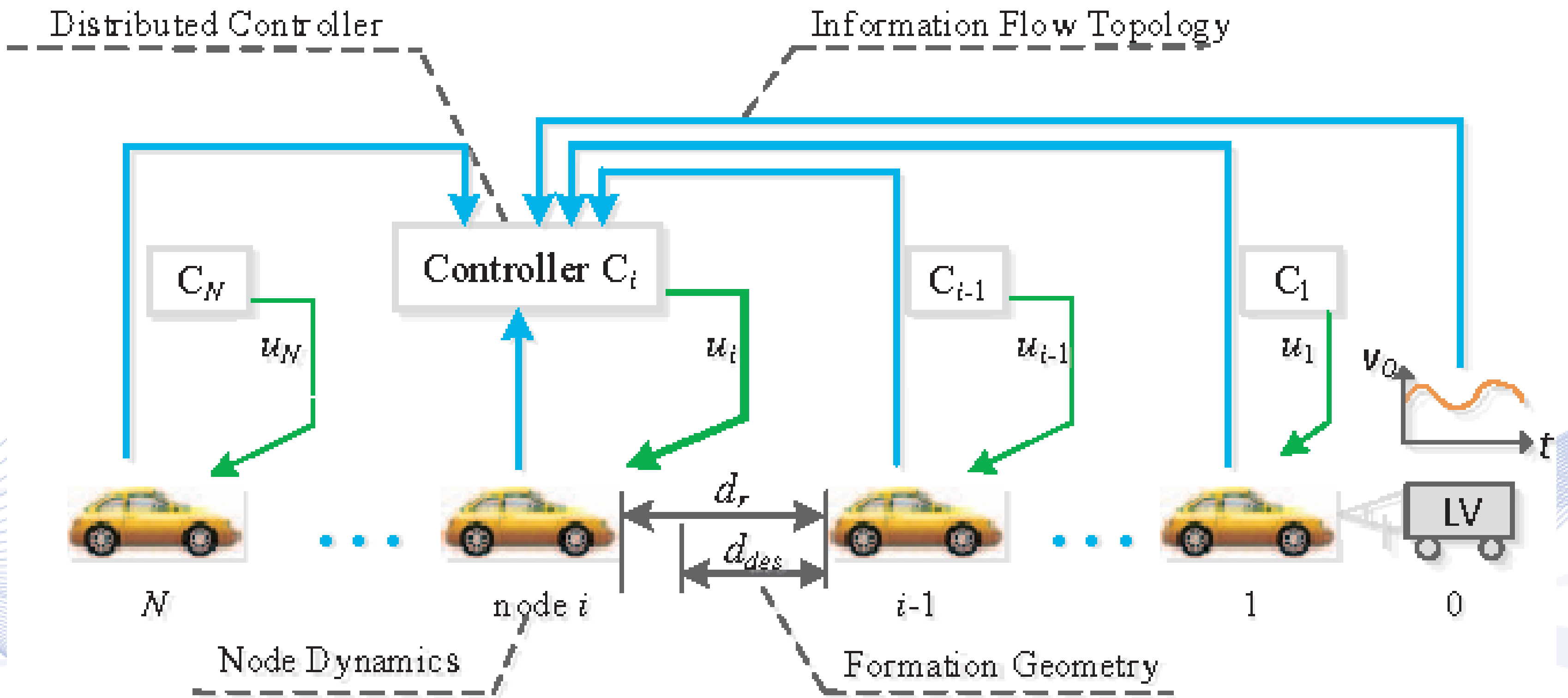
- Disaster Recovery
  - The use of UASs are extremely useful in dangerous environments
- Defense
  - Intelligence acquisition
  - Combat search and rescue
  - Post-nuclear radiation detection
- Reconnaissance, inspection, mapping
  - Easier for a swarm that a man or a single robot

Goals and Applications

- Farming and Food Management
  - Smoke and odors tracking
  - Migration od marine life
- Space systems
  - Location and re-direction of water/ice sources
  - Creation of massive antenna pattern through synchronized signals

Autonomous Car swarms

- Car platoon control



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Autonomous car swarms

- Lane-less highways
- Collision avoidance
- Fluid dynamics principles

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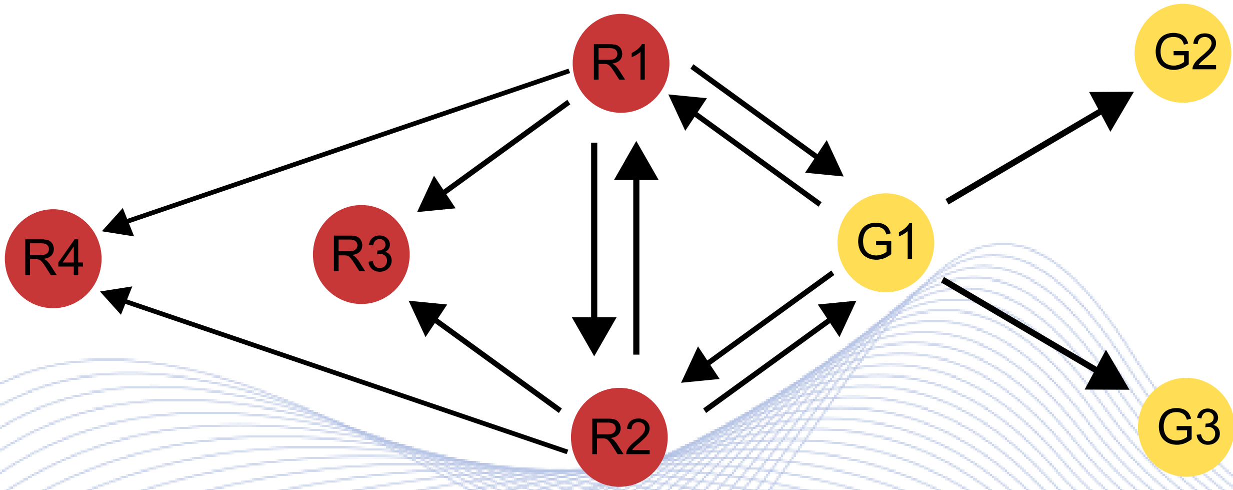
Drone Communications

In swarm robotics, each robot/drone collects data and:

- Broadcast to all the other members on the swarm
- Broadcast to the neighbors
  - Neighbors are the members inside a specific range from the robot/drone
- Transmit to the leader
- Transmit to the control station/human operator

Drone Communications



Drone Communications

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Architecture

Architecture of a swarm is the way each part of it communicates with the other and how this controls the way swarms achieves its goals

A possible architecture can be implemented with an ad-hoc network [2]

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Architecture with ad-hoc network

The swarm consists of:

- Exactly one leader drone *L*
- Exactly one control station *C* operated from a human
- Several drone-members

Let assume the task of target searching, in which the swarm has been assign to find a specific target indoors or outdoors (consider target searching in extended areas)

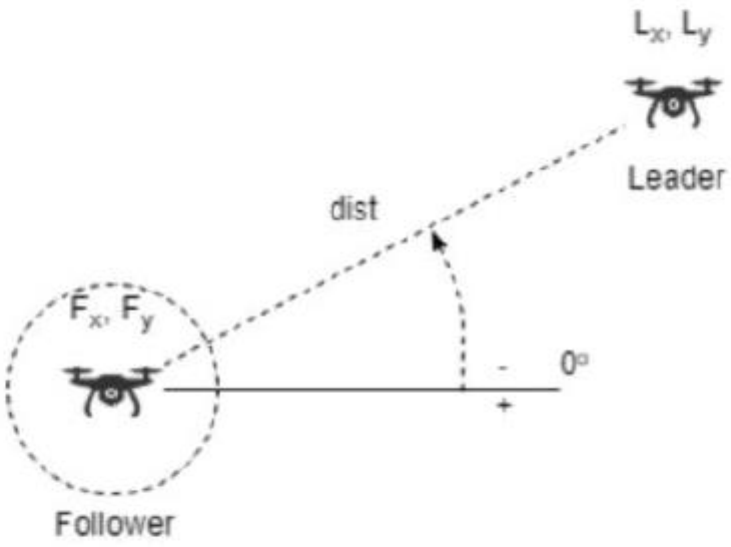
Formation

Very important task is the trade off between:

- Distributed formation control and maintenance
- Collision avoidance between the robots and obstacles

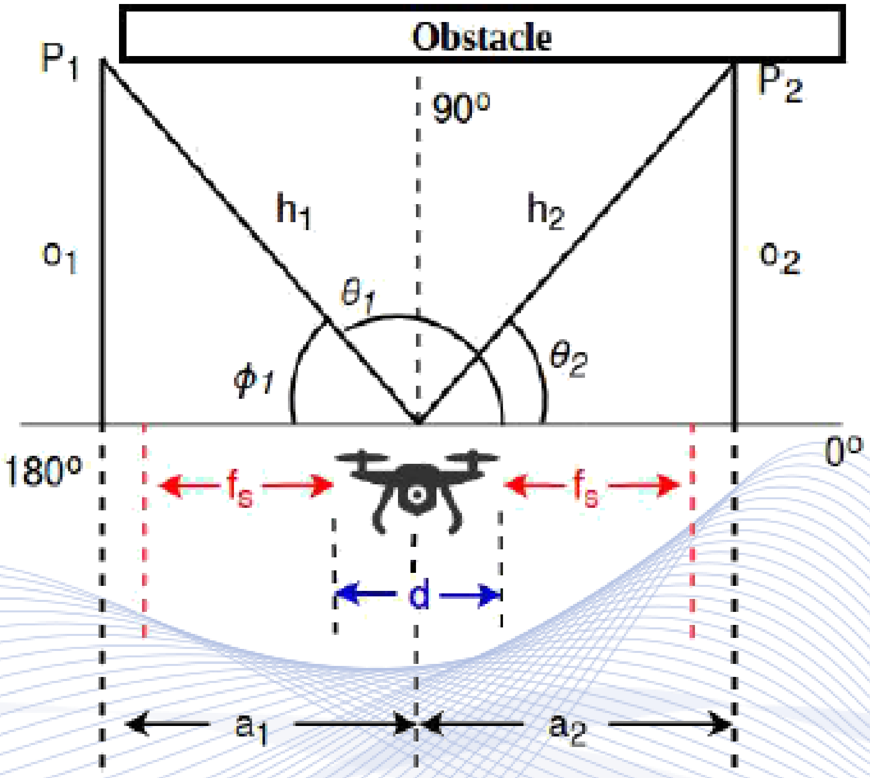
Regarding given system constrains (e.g. energy or response time)

Formation



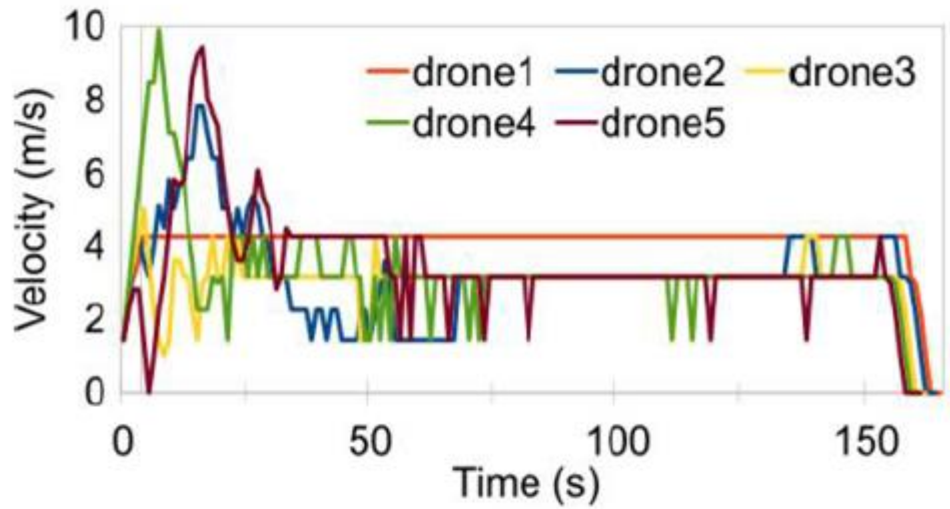
Distance and Direction Calculation (from [3])

Formation

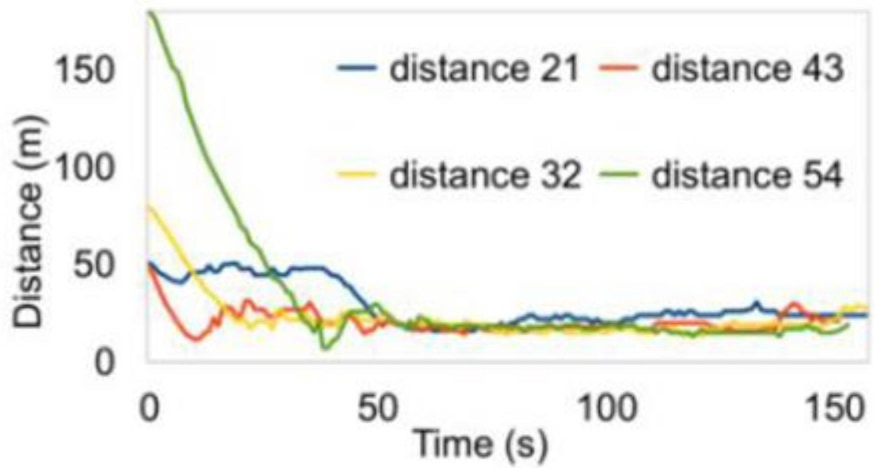


Obstacle detection and avoidance (from [3])

Formation



(a) Distance of each drone from its respective leader

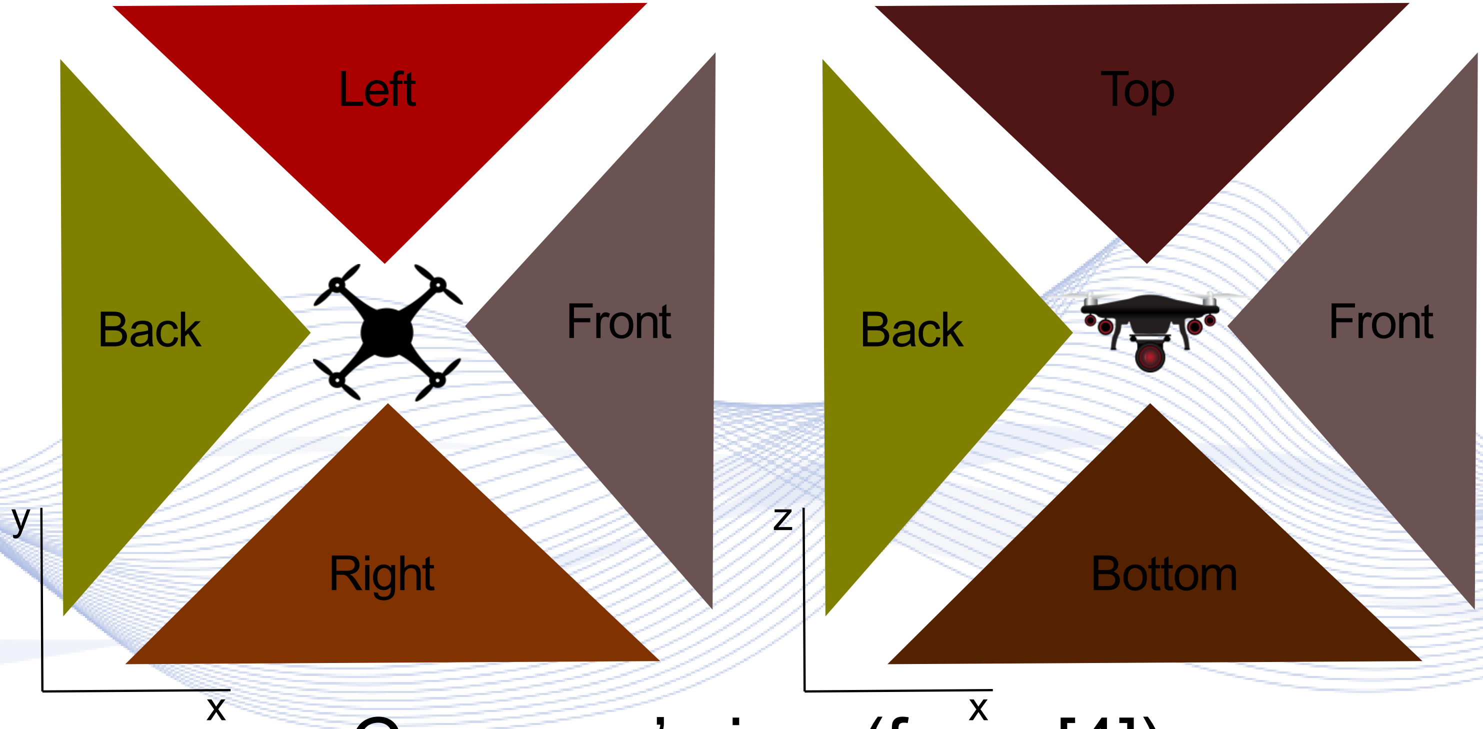


(b) Velocities of all UAVs

Plots of distance and velocity (from [3])

De-centralized Formation

Every drone is equipped with cameras looking in all directions.



Cameras' view (from [4]).

De-centralized Formation

Example visual data from one agent (from [4])

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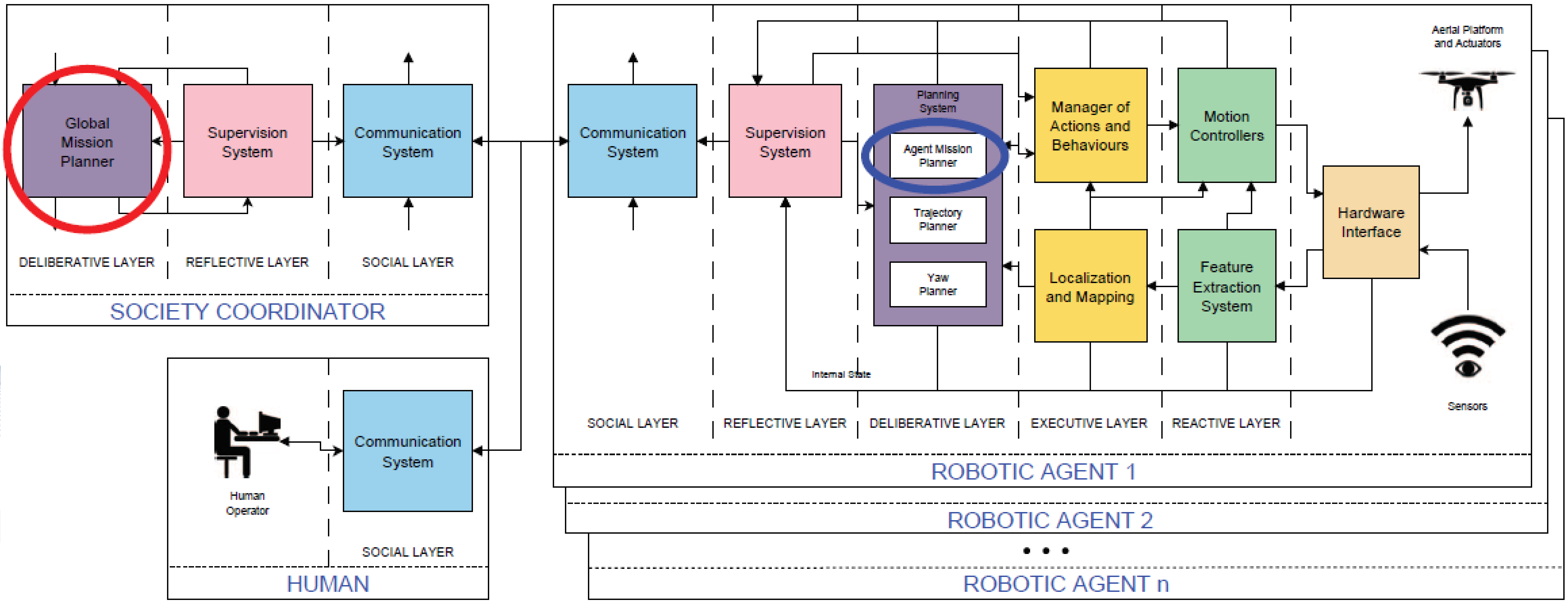
Mission Planning

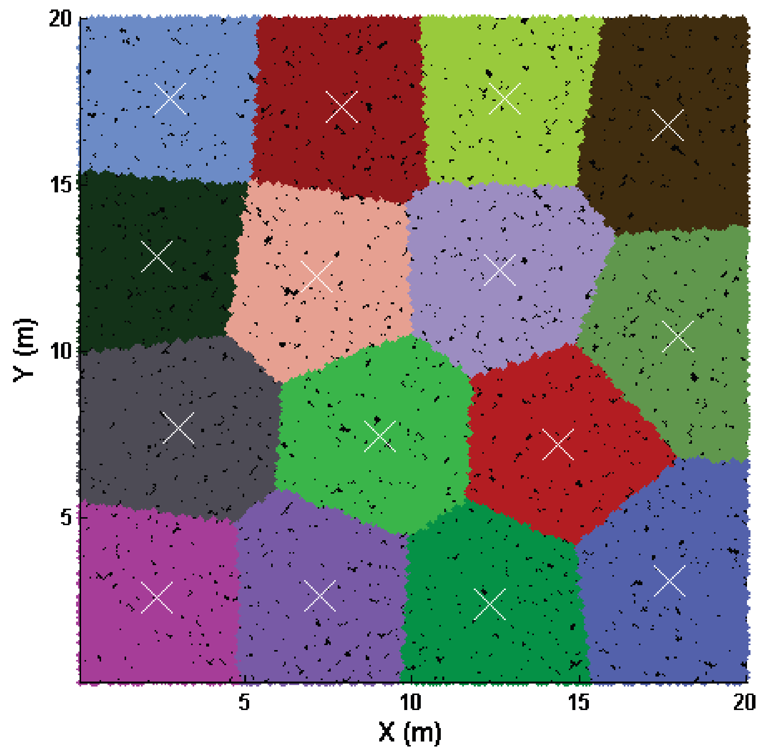
- A robot/drone can manage and accomplish a given task.
- A bigger task (e.g., target searching) can be separated in smaller task executable by a single robot.
- How does the agents of the swarm can be informed on which task to accomplish?
  - Master – slave
  - Insects communications
  - Total de-centralized approach

Mission Planning



System Architecture (from [5])

Mission Planning - GMP



Region sampling - Step 1 of GMP (from [5])

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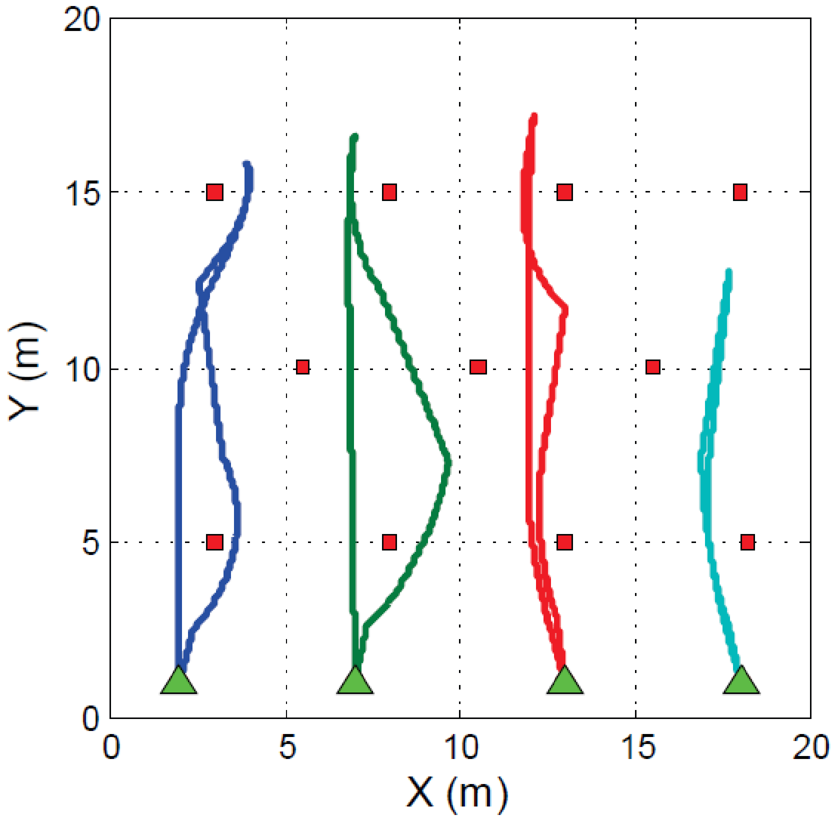
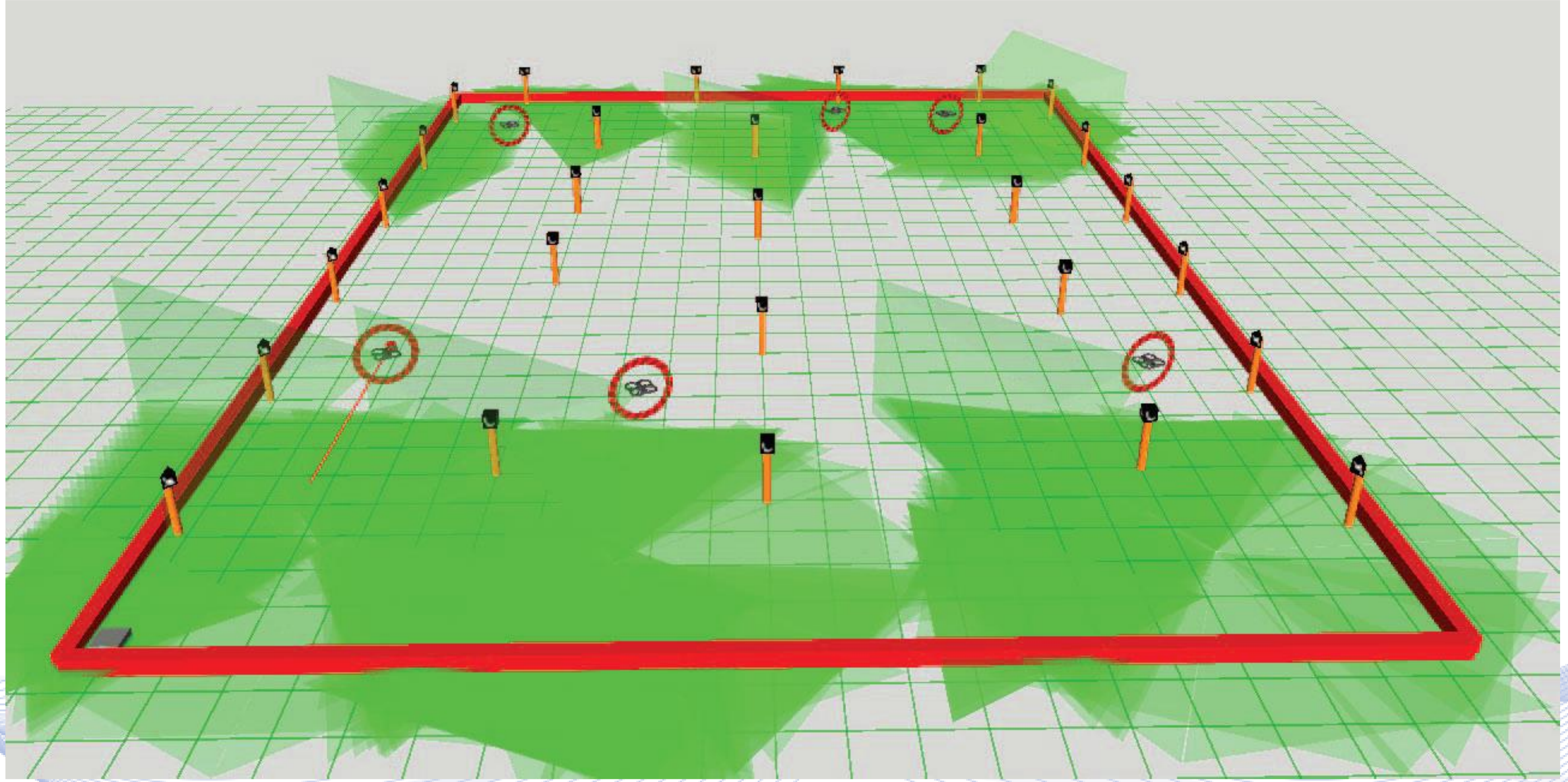
Mission Planning



Trajectories performed by 4 UAVs searching target located in (3, 15) (from [5])

Mission Planning



Explore mission in a $20 \times 30\, m^2$ map with 6 UAVs and 12 Obstacles (from [5])

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Algorithms

Swarm robotics can be used to solve multiple theoretical problems:

- Function optimization
- Construction of optimal solution – least path (TSP)

Algorithms

Many algorithms used in swarms are inspired by biological swarm intelligent and behavior of social insects:

- Ant colonies can find the shortest path to foraging source

These tactics can be applied to an artificial swarm in order to solve theoretical problems like shortest path in a graph

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Algorithms - ACO

Social insects:

- Swarm Intelligence
  - Division of labor among nestmate
- Self-organization
  - Decentralized problem-solving system
- Individual capabilities
  - Able to discriminate between nestmate and not

Algorithms - ACO

How real colonies operate:

- Each ant start from the nest looking for foraging source
- If an ant finds a source of food, return to the nest releasing a chemical substance called pheromone
- The ants starting from the nest, tent to follow the way with the most pheromone on it, with a specific probability
- The pheromone evaporating through the time, decreasing the possibility of an ant to choose these way

Algorithms - ACO

How to simulate real colonies tactics:

- Let assume a graph $G = (V, E)$ and T the possible paths between two specific vertices (start, end)
- The amount of pheromone on a path i is:

$$\tau_i = \tau_i + \frac{Q}{l_i}$$

- The probability of a robot chose path i is:

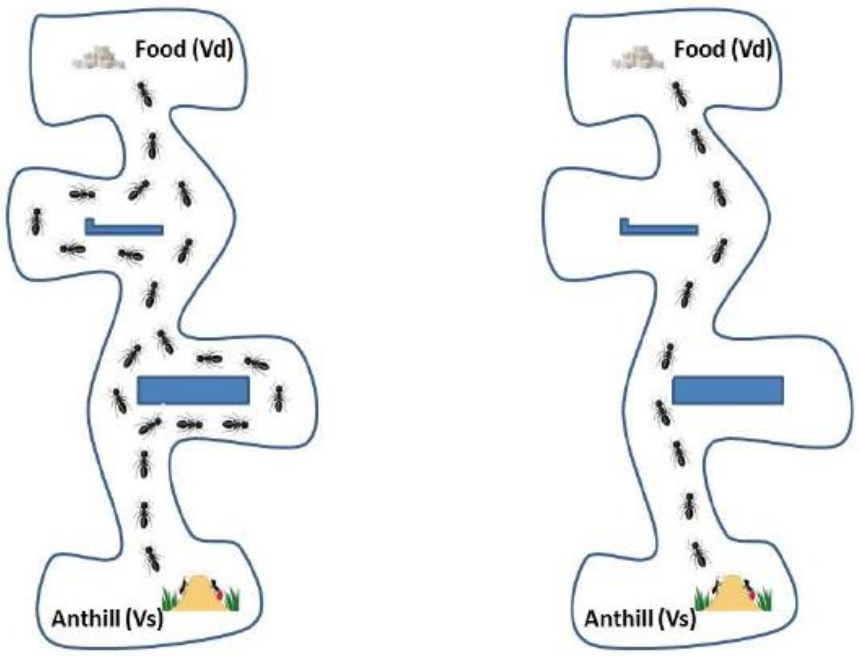
$$p_i = \frac{\tau_i}{\sum_{\tau_i \in T} \tau_j}$$

- The trail pheromone evaporation is:

$$\tau_i = (1 - p)\tau_i$$

where p is constant evaporation probability in every iteration

Algorithms - ACO



Shortest path finding (from [6])

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  - **PSO**
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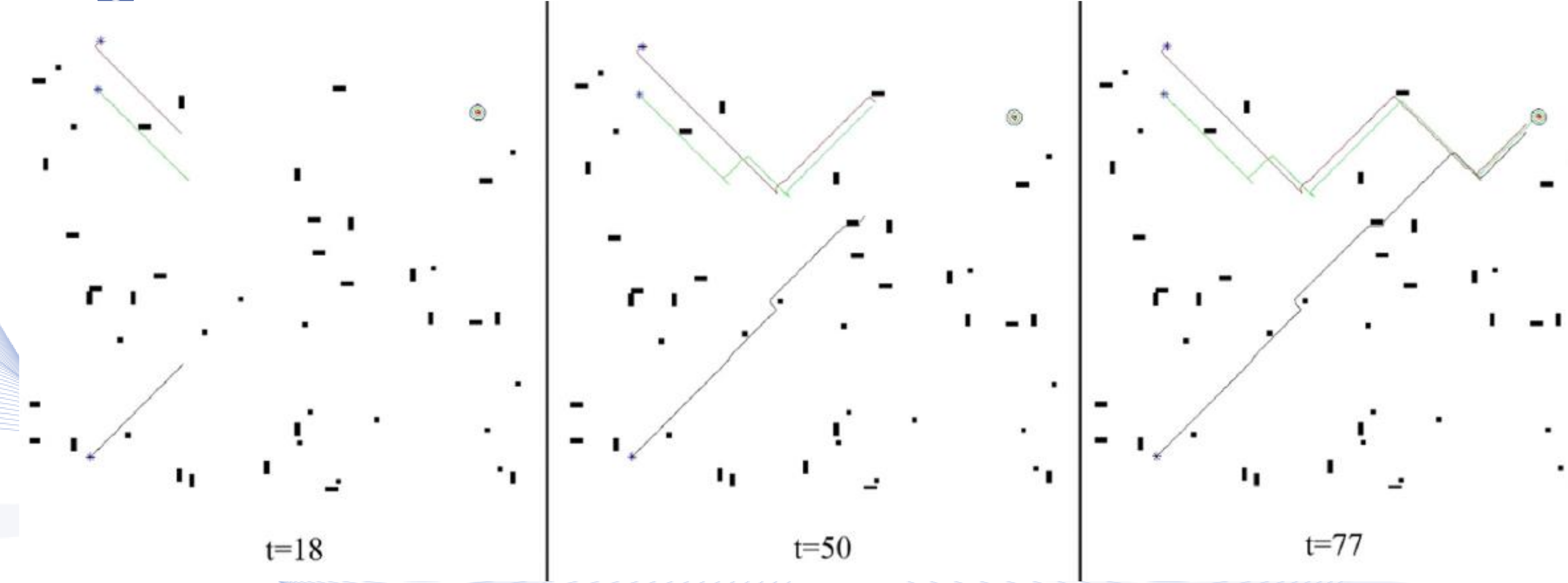
Algorithms - PSO

- PSO stands for Particle Swarm Optimization.
- A heuristic technique
- It is used for solving complex optimization problems
  - Clustering and classification
  - Security
  - Modeling
  - Communication networks
  - Signal processing
  - Path planning

Algorithms – PSO extensions



Target searching example using A-RPSO (from [7])

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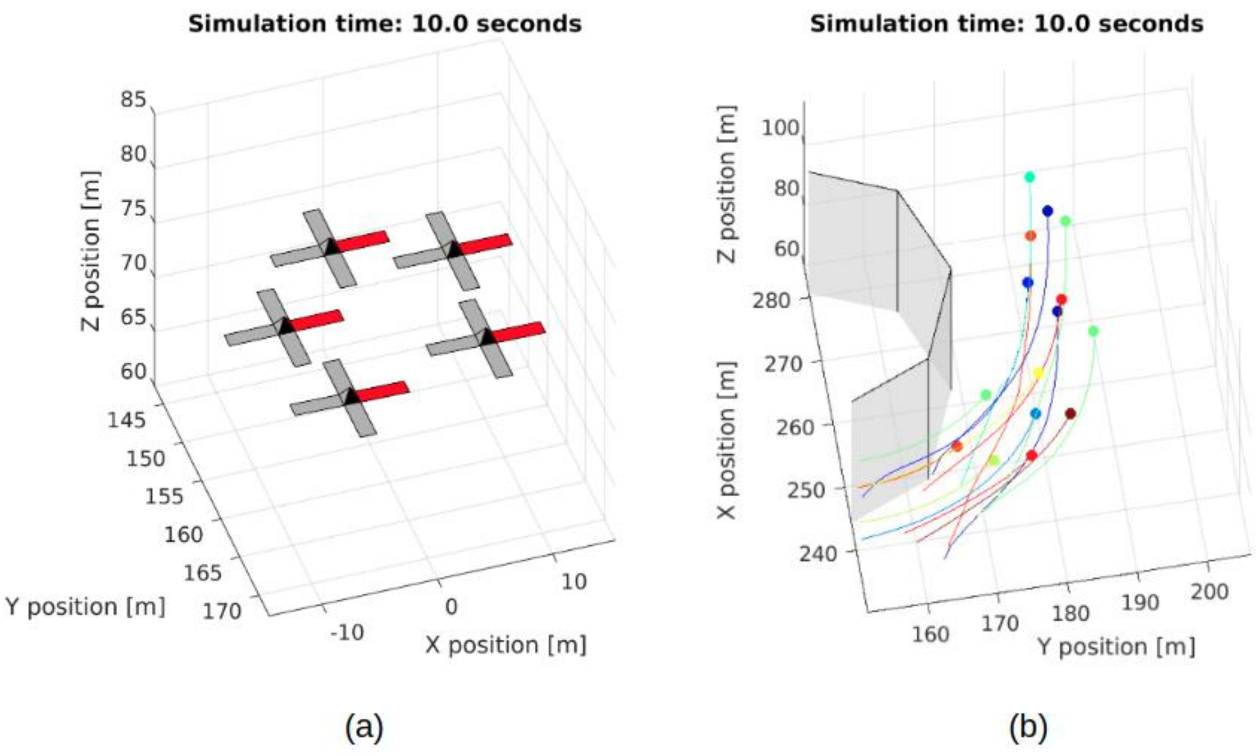
Simulators

- A drone simulator is extremely importation in swarm robotics research because let us focus on the algorithms (architecture, formations, planning) without considering about real robots/drones
- Moreover, a good simulator save us money and time that real experiments indoor or outdoors requires

Simulators



(a) Drones as quadcopters (realistic)
(b) Drones as particles (approximation) (from [8])

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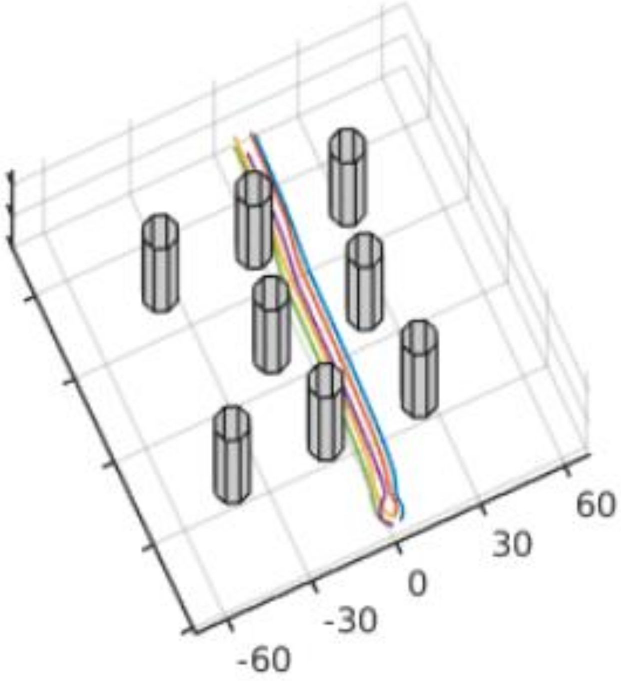
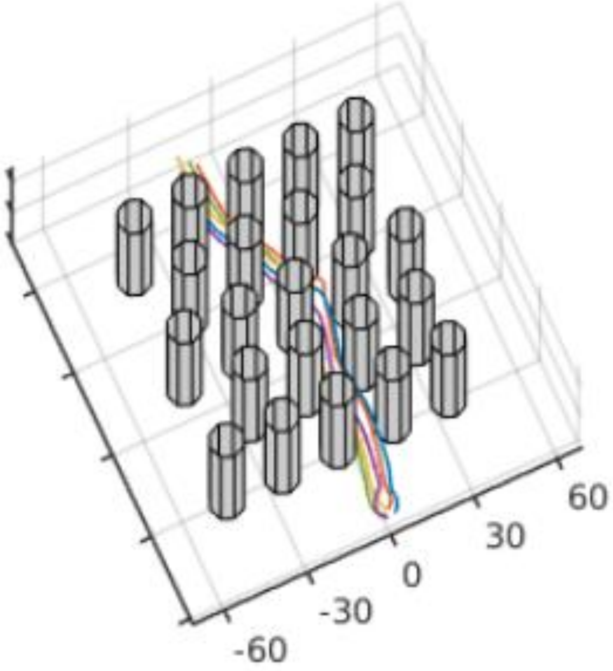
Simulators





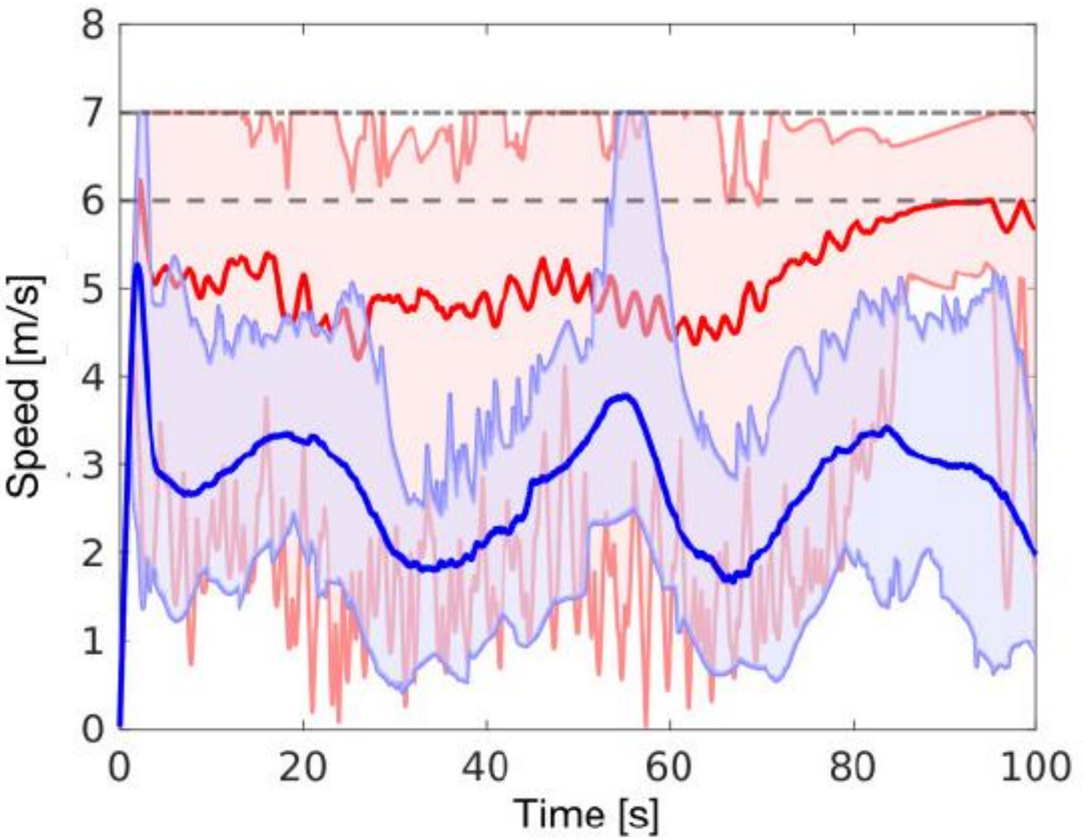
Simulation with cylindrical obstacle and drones as particles (from [8])

Metrics

What metrics can a simulator use to evaluate the success of a design or an algorithm?

- order metric, $\Phi_0 = \frac{1}{N(N-1)} \sum_{i,j\neq i} \frac{\boldsymbol{v}_i \cdot \boldsymbol{v}_j}{\|\boldsymbol{v}_i\| \|\boldsymbol{v}_j\|}$
- safety metrics $\Phi_{s,ag} = 1 - \frac{n_{ag}}{N(N-1)}$ and $\Phi_{s,obs} = 1 - \frac{n_{obs}}{N}$
- union metric $\Phi_u = 1 - \frac{n_c - 1}{N-1}$
- connectivity metric $\Phi_c = \frac{\lambda_2}{N}$

Simulators



Plot example (from [8])

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Q & A

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