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Robust Communication-aware Jamming Detection and Avoidance

Samuel Peccoud (CSU)

Sang Xing (PSU)

Dr. Yang (ERAU)

ERAU NSF REU

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Research Questions

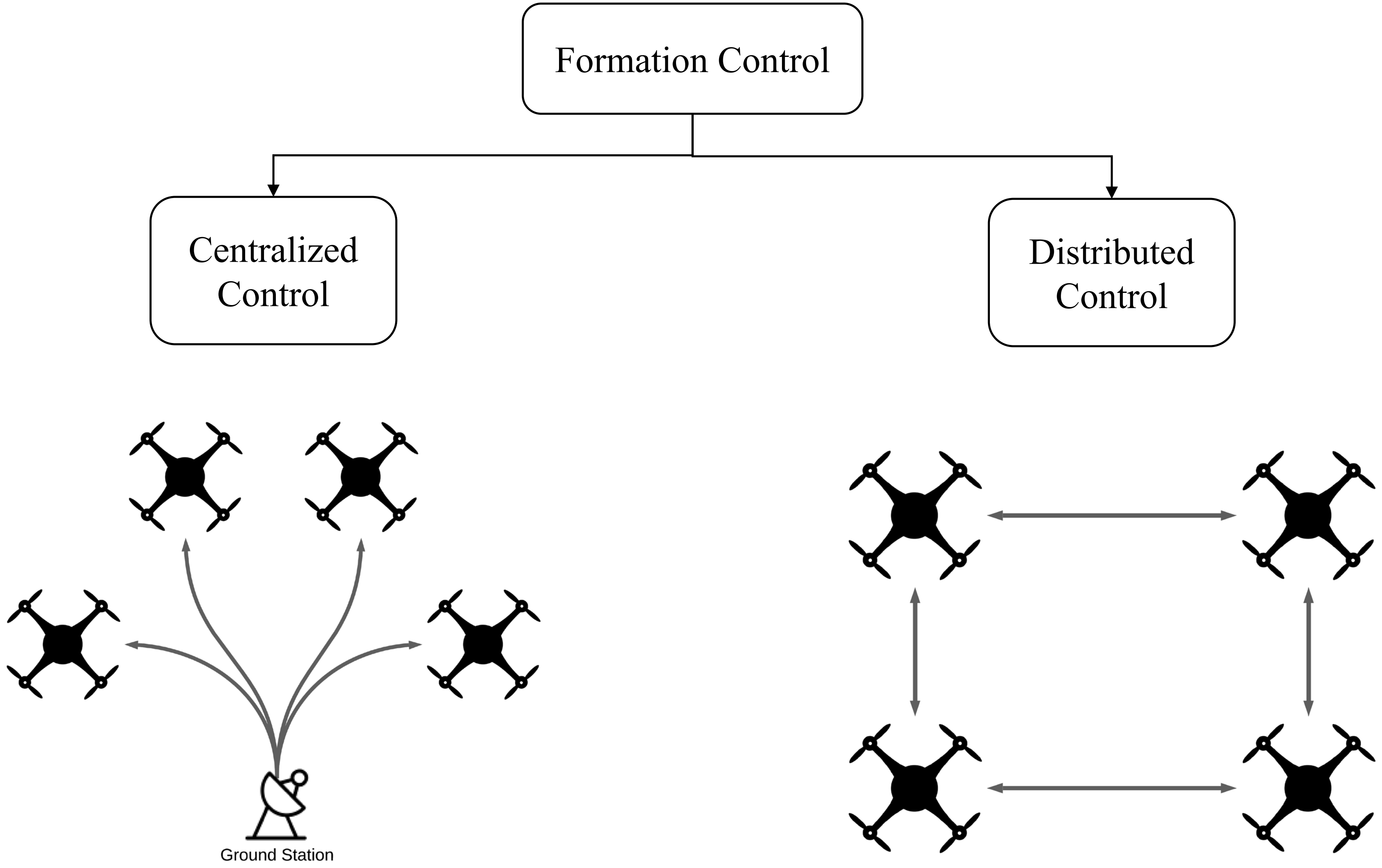
1. How to navigate a swarm around jamming areas?

- Particle Swarm Optimization (PSO) Algorithm + Path Planning Algorithm

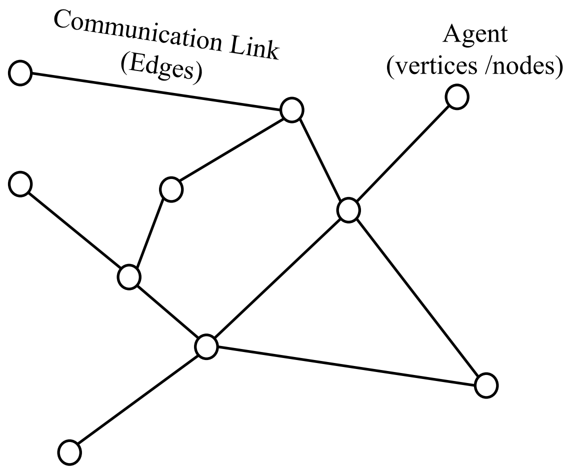
2. How to maximizing communication quality between agents?

- Communication-aware formation control

Background


Formation Control
Centralized Control
Distributed Control
Ground Station

Preliminaries



Graph Theory

A **graph** G is a pair of $(\mathcal{V}, \mathcal{E})$ consisting of a set of **vertices** $\mathcal{V} = \{1,2, \dots, i, \dots, j, \dots n\}$ and a set of ordered pairs of the vertices called **edges** $\mathcal{E} \subseteq \mathcal{V} \times \mathcal{V}$. I.e., $\mathcal{E} = \{(i,j) | i,j \in \mathcal{V},\ i \neq j\}$. Here, we assume that G has no **self-edges** and **undirected**.

Rigid Formation

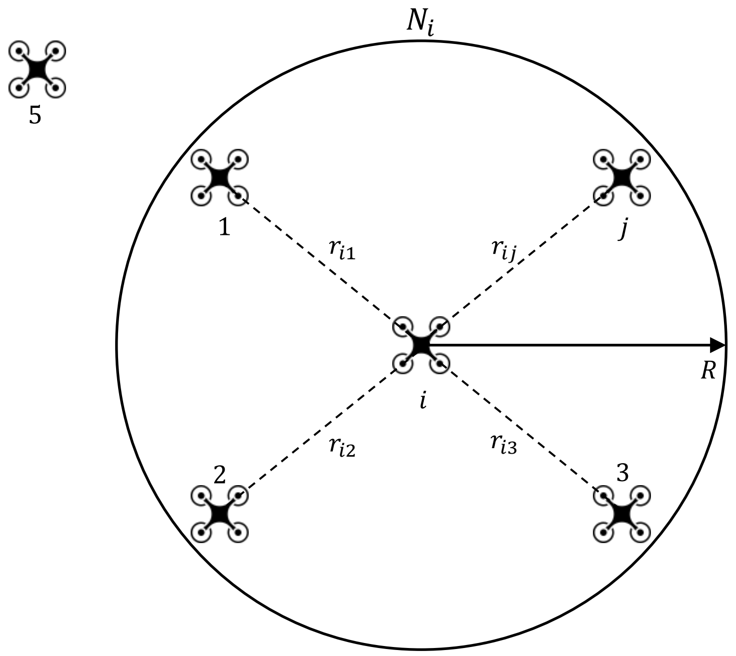
The formation of groups of mobile agents in which all inter-agent distances remain constant is called **rigid**.

The **relative distance** between agent i and agent j is denoted by

$$r_{ij} = \sqrt{\left(x_i - x_j\right)^2 + \left(y_i - y_j\right)^2} = \|q_i - q_j\|.$$

Let $R > 0$ denote the **communication range** between two agents. The neighboring set of agent i can be denoted by

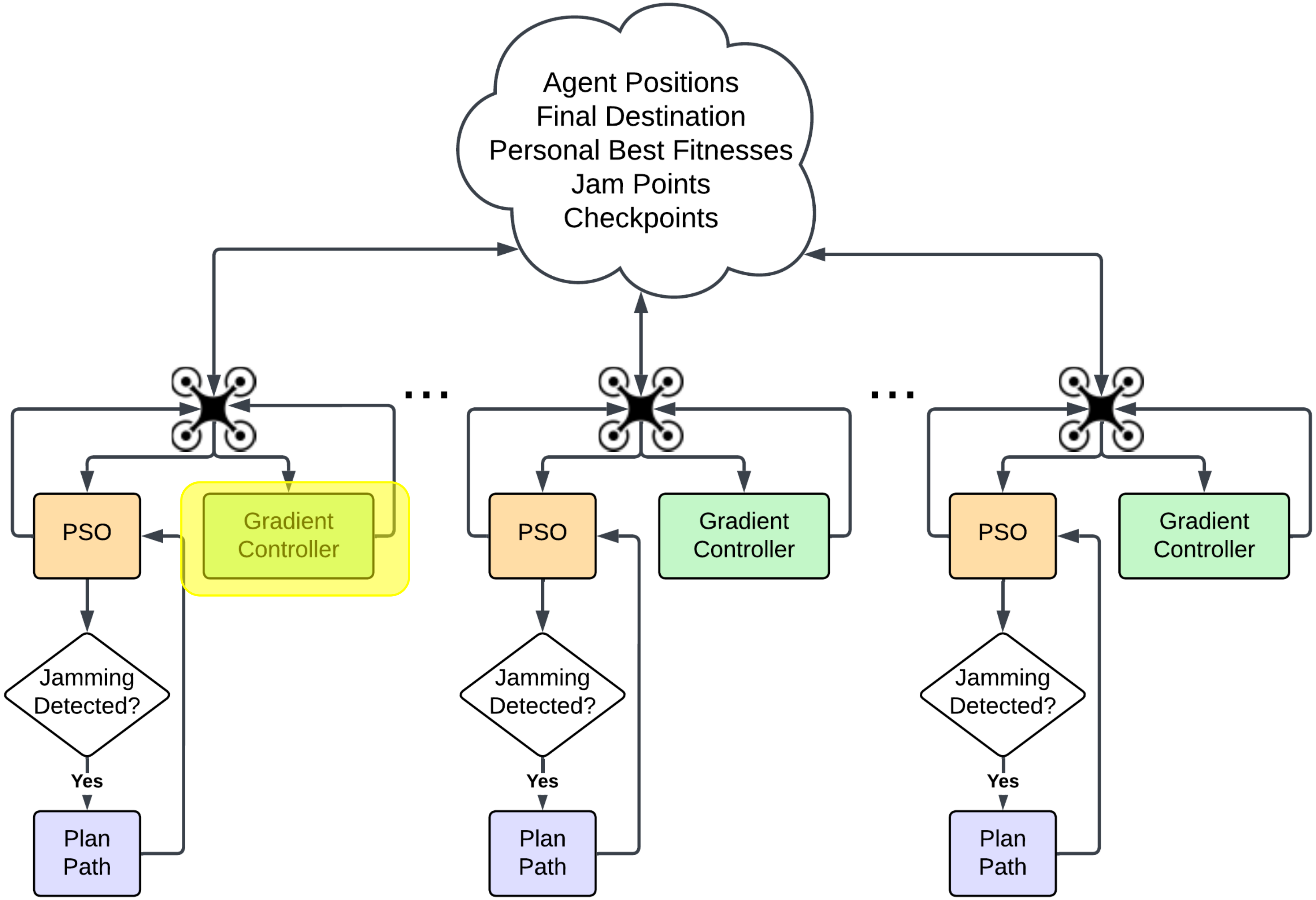
$$N_i = \{j \in \mathcal{V} \mid r_{ij} \leq R\}.$$



Schematic Diagram

Legend

- Shared Data
- Updates Personal Fitness
- Detects Jam Points
- Creates Checkpoints

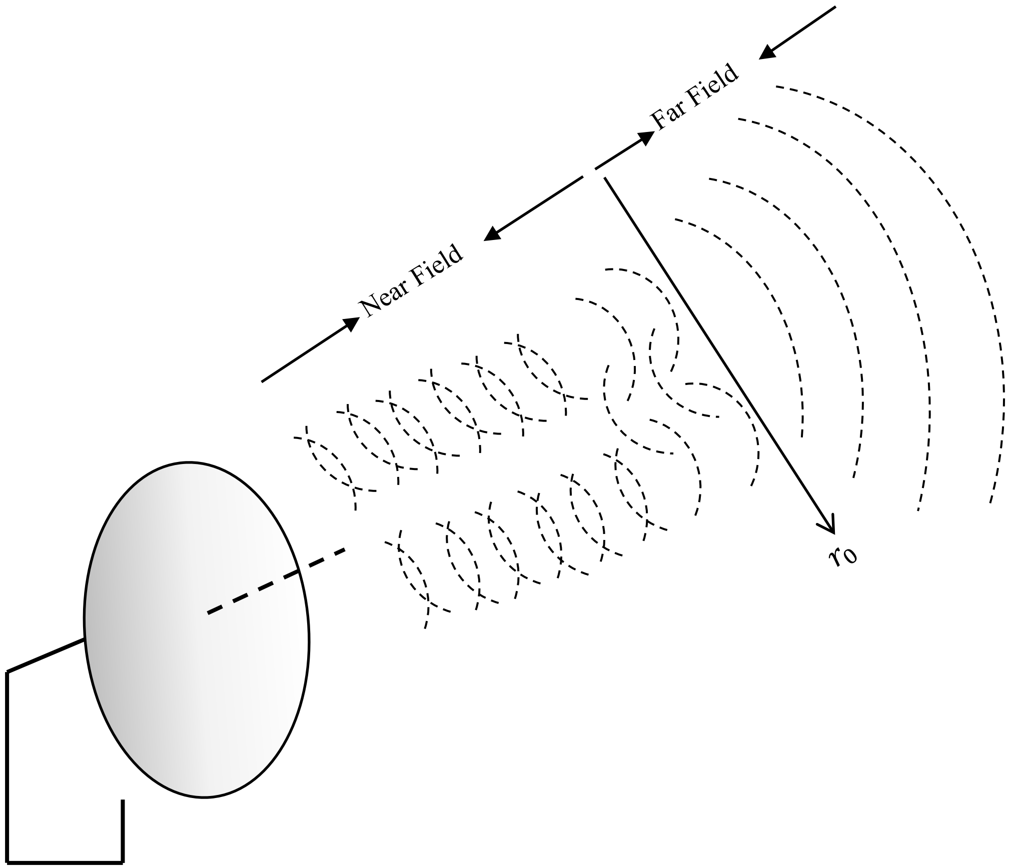


02

Communication Model

- Antenna Near-field and Far-field
- Interaction Model

Antenna Near-field and Far-field



Far-field

The communication channel quality in antenna far-field is:

$$f_{ij} = \exp\left(-\alpha\left(2^{\delta}-1\right)\left(\frac{r_{ij}}{r_0}\right)^{v}\right).$$

Near-field

A simple model of antenna near-field communication quality is:

$$n_{ij} = \frac{r_{ij}}{\sqrt{{r_{ij}}^2+{r_0}^2}}$$

where

r_0: antenna field separator,

r_{ij}: distance between agent i and agent j.

Interaction Model

Signal Scattering Effect

When a traveling wave encounters a change in the wave impedance, it will reflect, at least partially. If the reflection is not total, it will also partially transmit into the new impedance.

Path Loss Effect

The reduction in power density (attenuation) of an electromagnetic wave as it propagates through space. As a result, the received signal power level is several orders below the transmitted power level.

Interference Effect

When a signal is disrupted as it travels along the communication channel between its source and receiver. It may cause only a temporary loss of a signal and may affect the quality of the communication.

Interaction Model

The interaction model is denoted by

$$\phi(r_{ij}) = n_{ij} \cdot f_{ij} = \frac{r_{ij}}{\sqrt{{r_{ij}}^2 + {r_0}^2}} \cdot \exp\left(-\alpha(2^\delta - 1)\left(\frac{r_{ij}}{r_0}\right)^v\right).$$

03

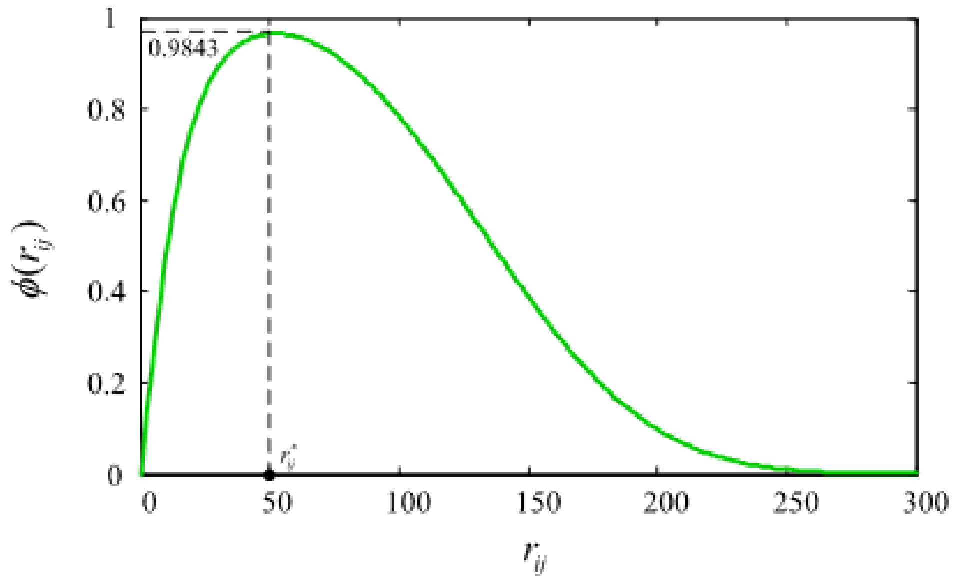
Control Layer

- ❑ Gradient Controller
- ❑ Movement Controller
    - Particle Swarm Optimization (PSO)
    - Path Planning

Gradient Controller

To maximizes the communication performance, we take the first-order derivative of the interaction model,

$$\frac{d\phi}{dr_{ij}} = \varphi(r_{ij}) = \frac{-\beta v (r_{ij})^{v+2} - \beta v r_0^2 (r_{ij})^{v} + r_0^{v+2}}{\sqrt{(r_{ij}^2 + r_0^2)^3}} \cdot \exp\left(-\beta \left(\frac{r_{ij}}{r_0}\right)^{v}\right).$$



A gradient controller moves agents to maximize communication performance.

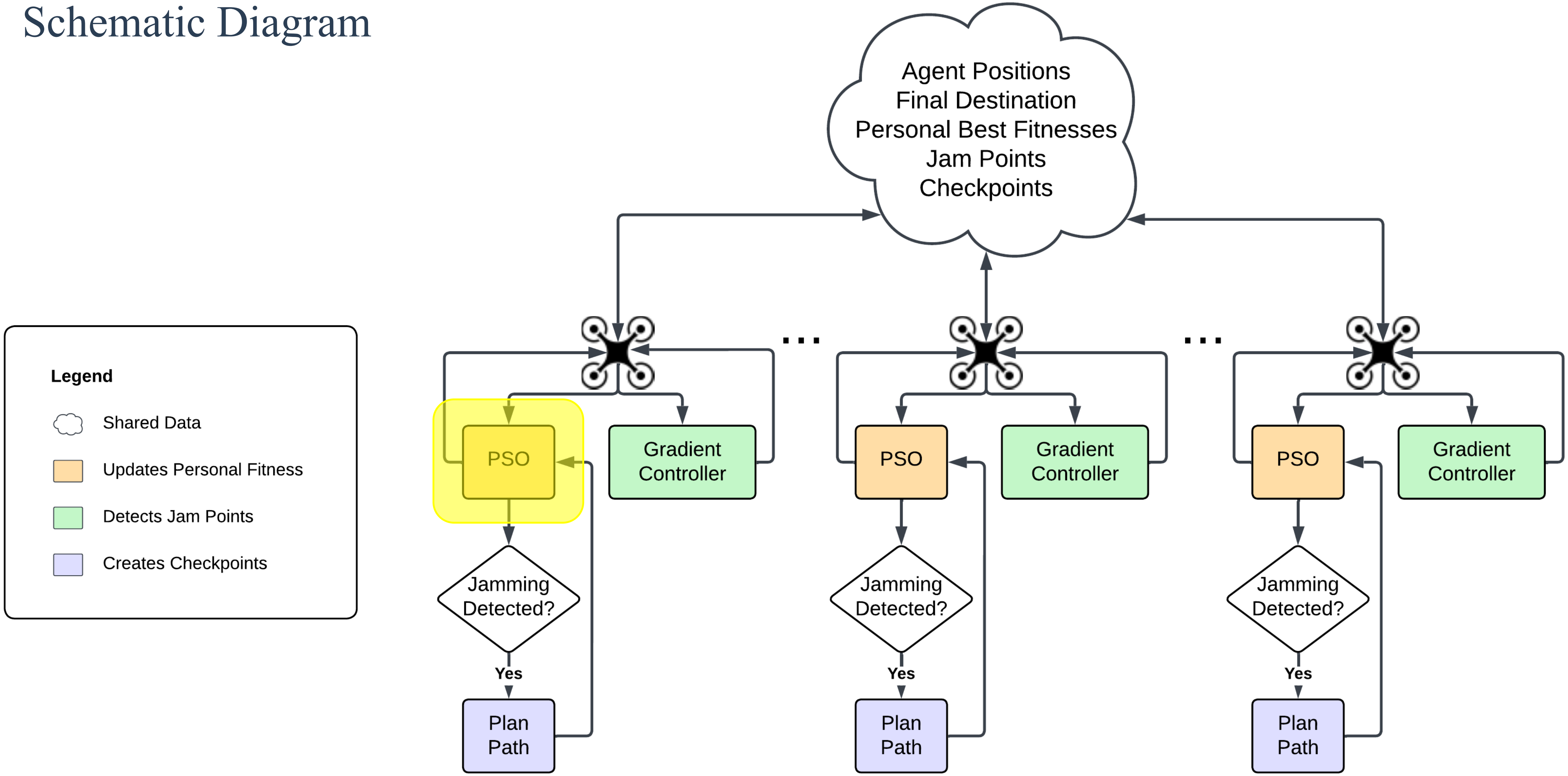
Gradient Control Model

The gradient control model of agent i is denoted by

$$\mathcal{G}_i = \sum_{j \in N_i} [\nabla_{q_i} \phi(r_{ij})] = \sum_{j \in N_i} [\varphi(r_{ij}) \cdot e_{ij}]$$

where $e_{ij} = (q_i - q_j)/\sqrt{r_{ij}}$.

Schematic Diagram



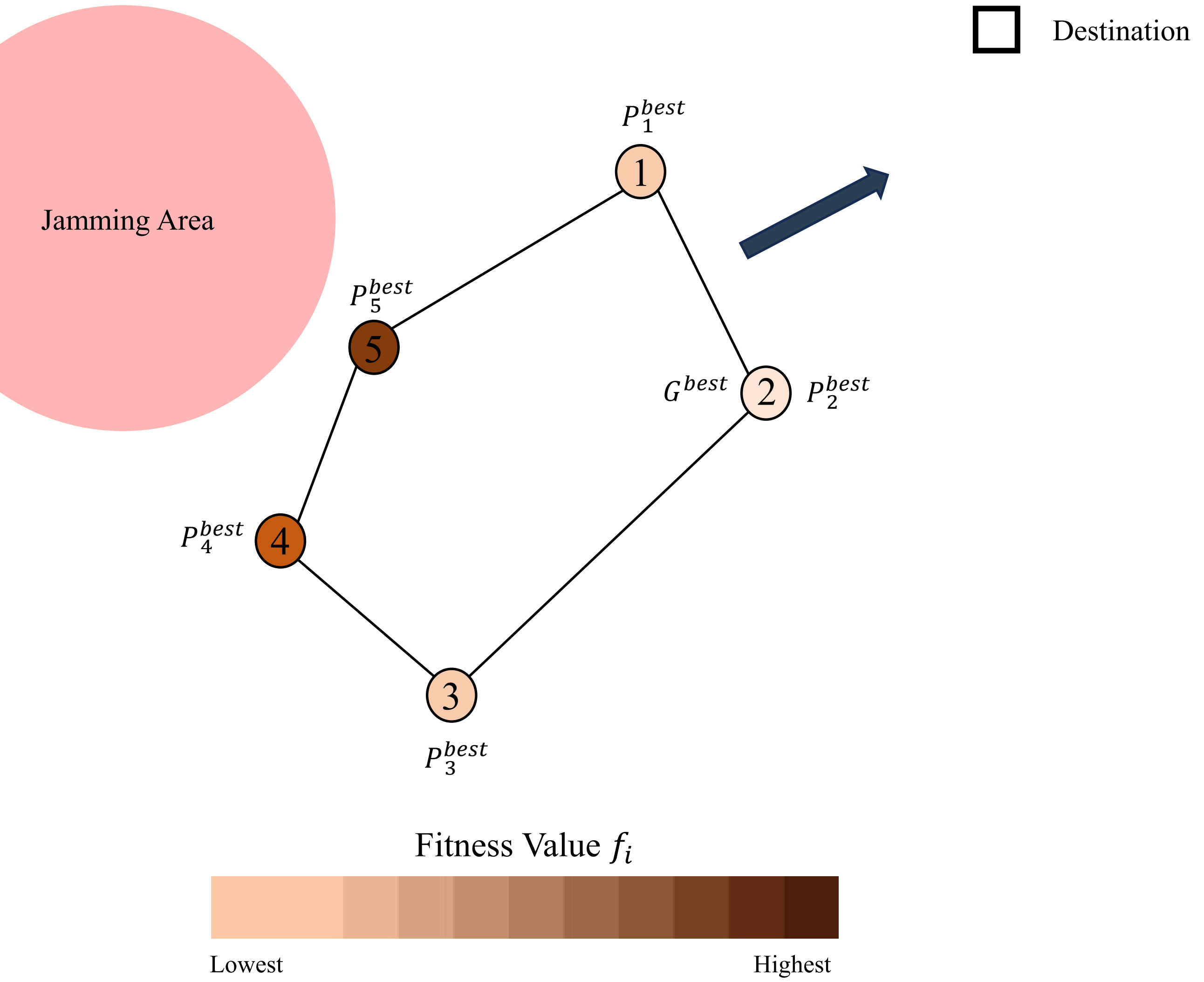
Particle Swarm Optimization

Particle Swarm Optimization (PSO) is a biology inspired algorithm.

It is commonly used in multi-robot path planning.

Photo by Don DeBold

Particle Swarm Optimization



Fitness Function

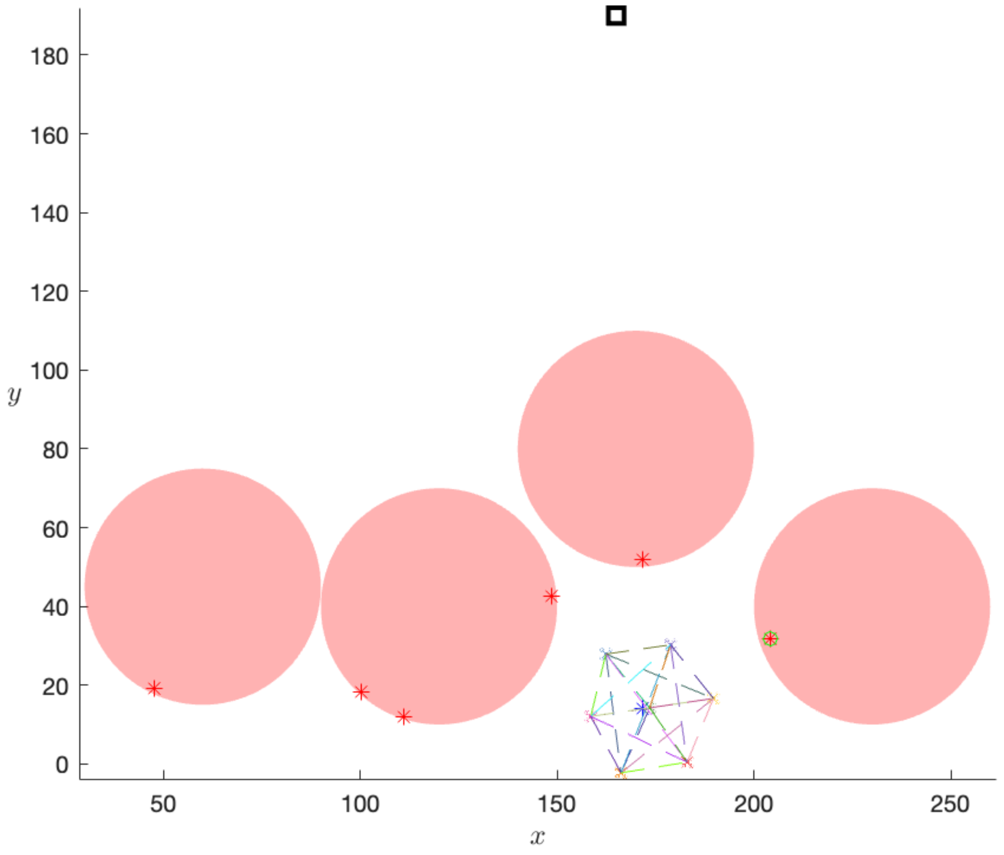
The fitness value of agent i is:

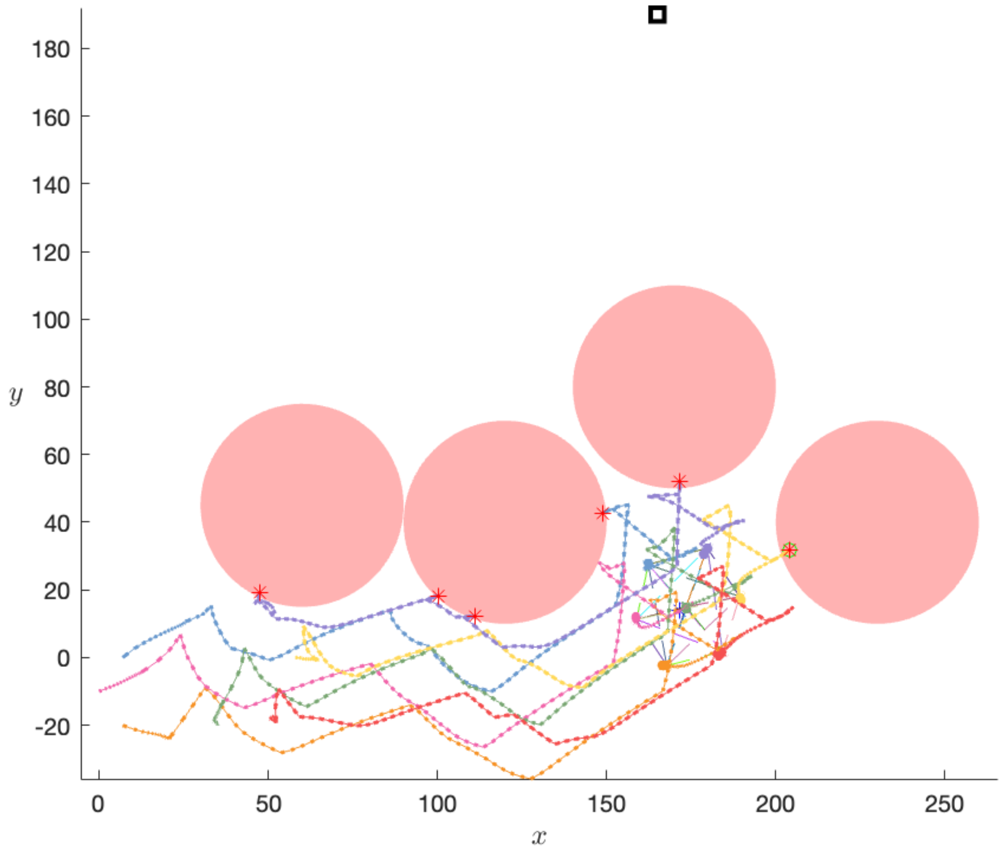
$$f_i = d_{\text{dest}} \cdot w_{\text{dest}} - \log_{10}\left(h_{\text{jam}}\right) \cdot w_{\text{jam}},$$

where

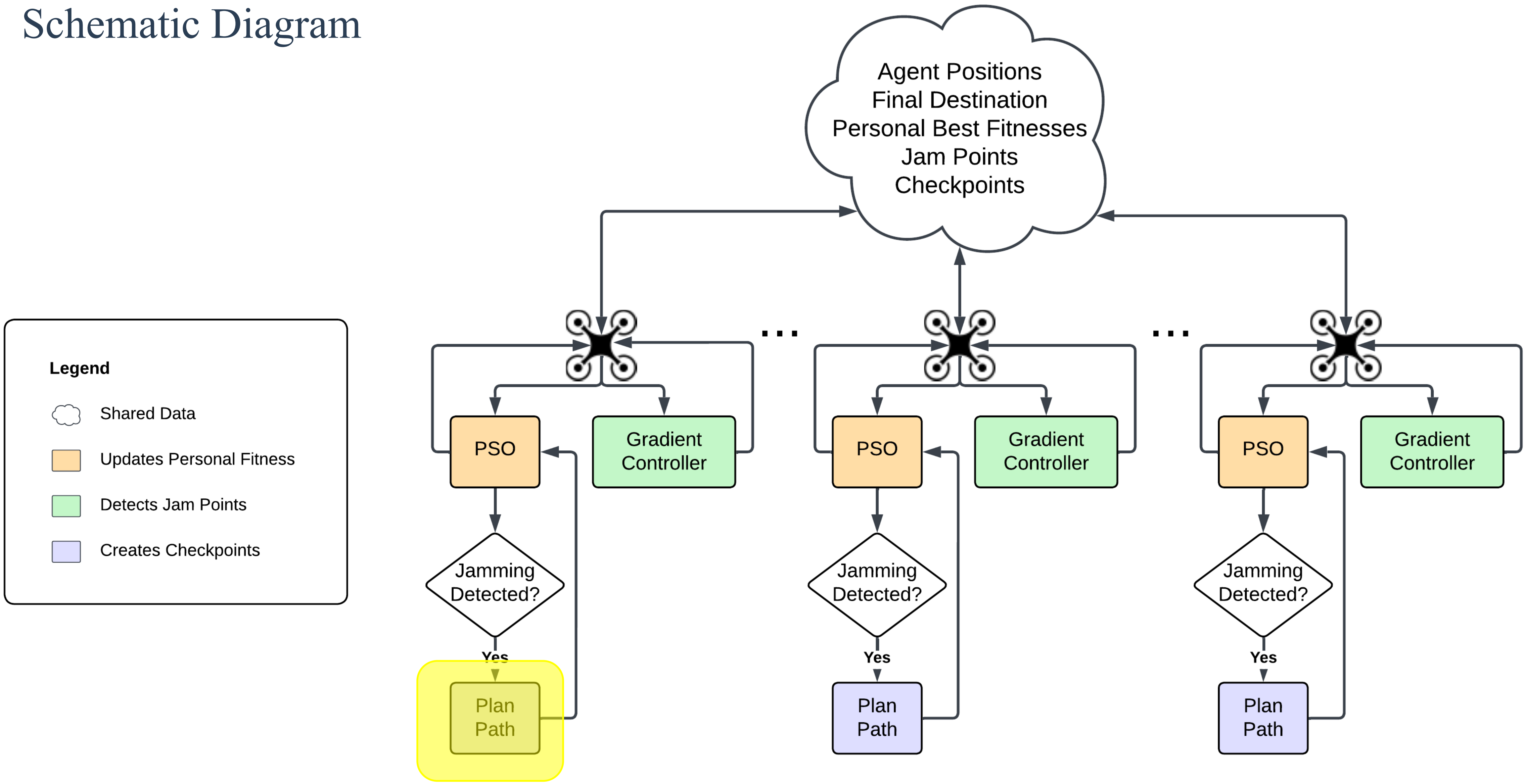
- d_{dest} is the distance from agent to destination.
- h_{jam} is the distance from agent to jam point.
- w_{dest} and w_{jam} are adjustable weight to the distance vector.

Particle Swarm Optimization

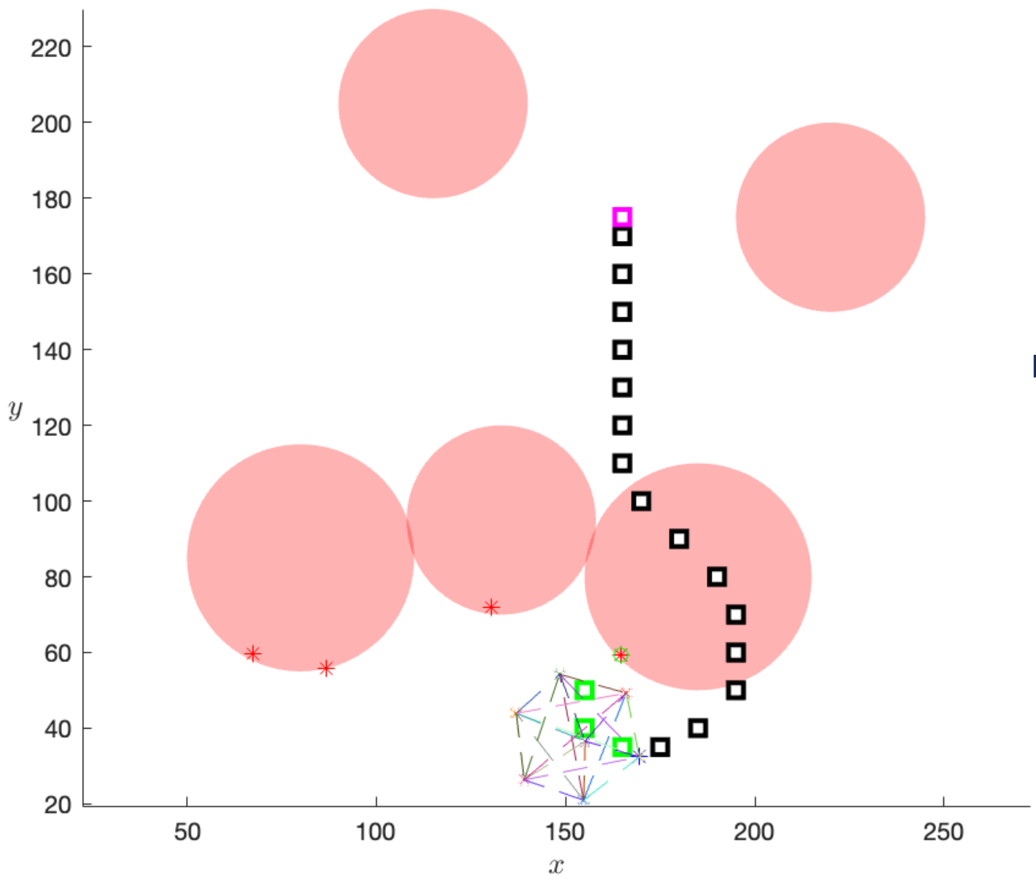




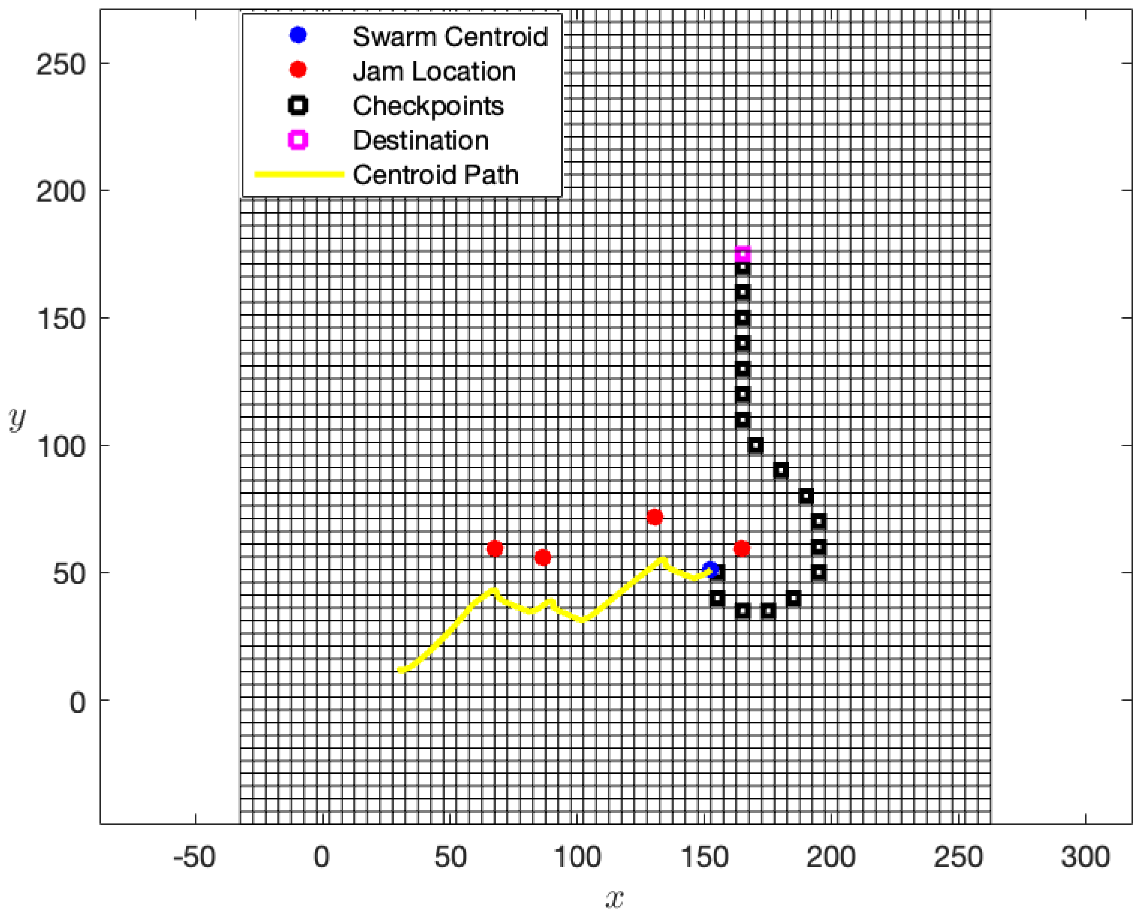
Schematic Diagram



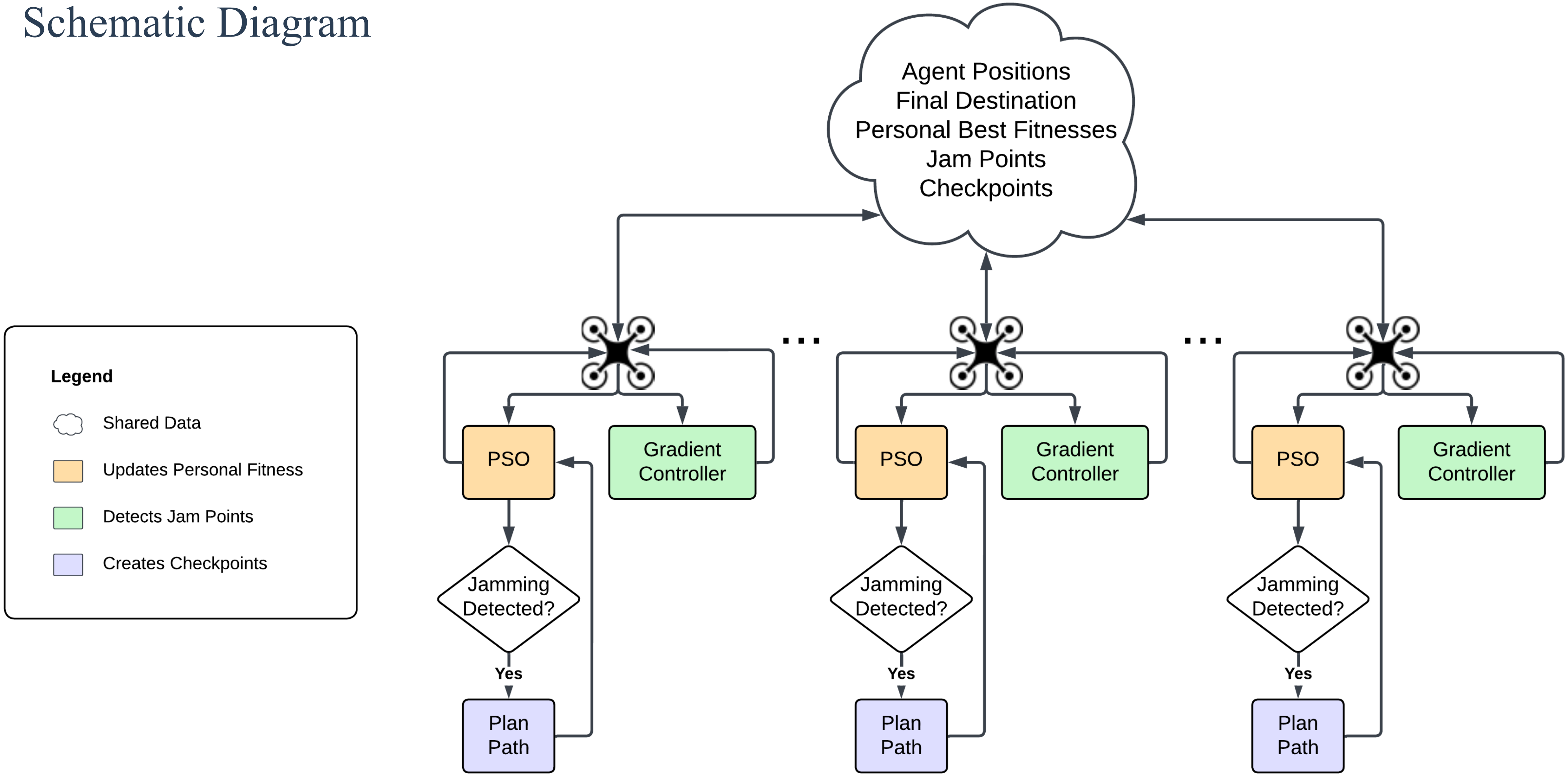
Path Planning Algorithm



Discretized Environment



Schematic Diagram

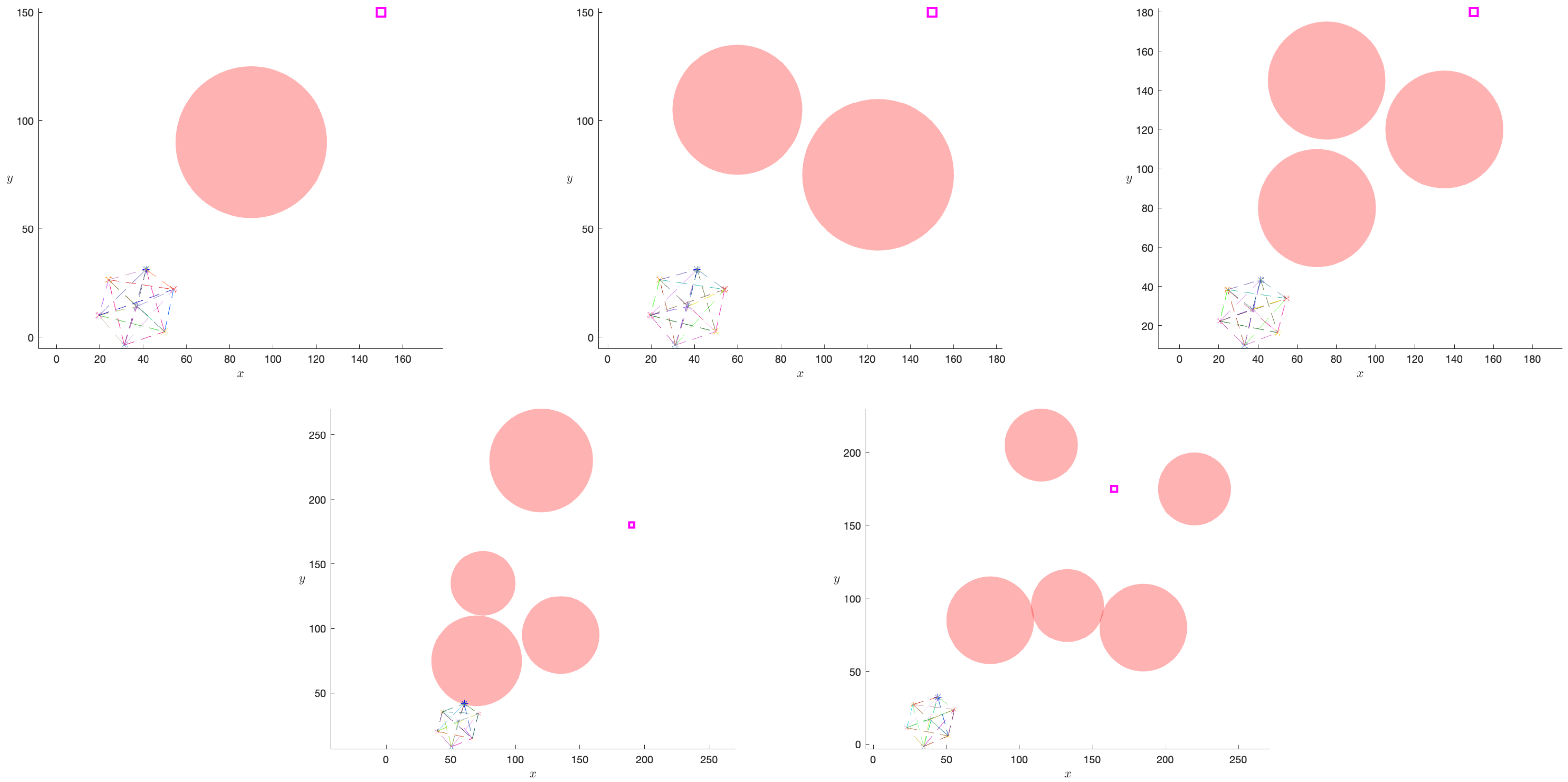


04

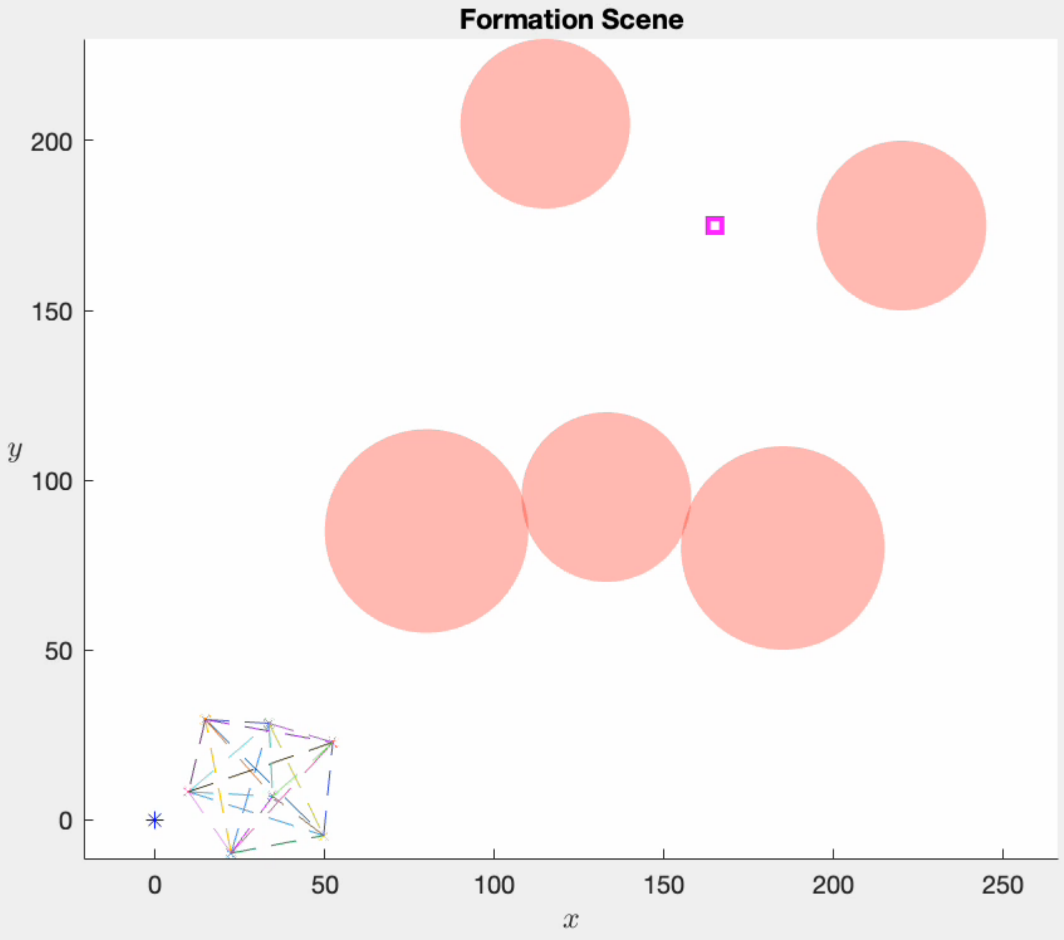
Simulations

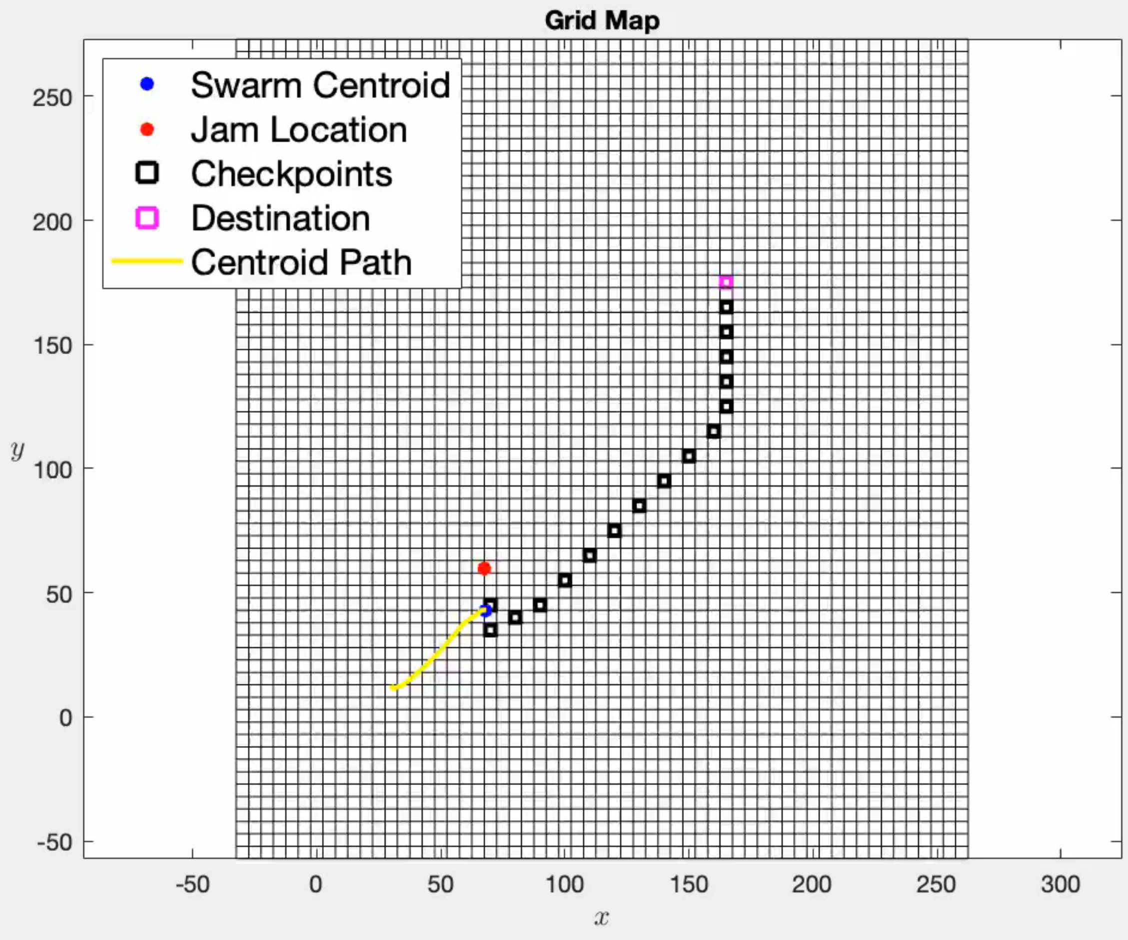
- ❑ Simulation Environments
- ❑ Simulation Results
- ❑ Simulation Evaluation

Simulation Environments



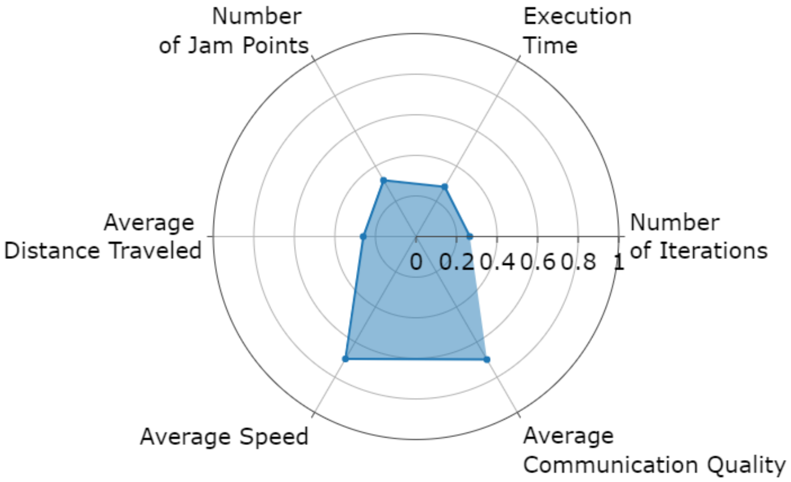
Simulation Results



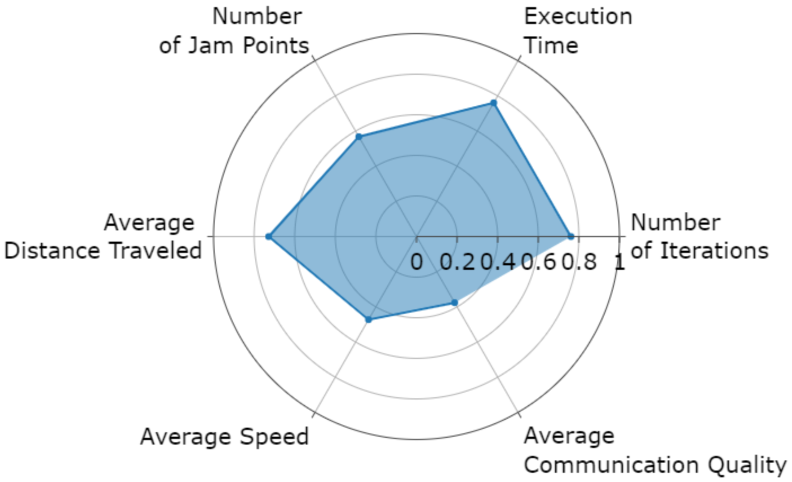


Simulation Evaluation

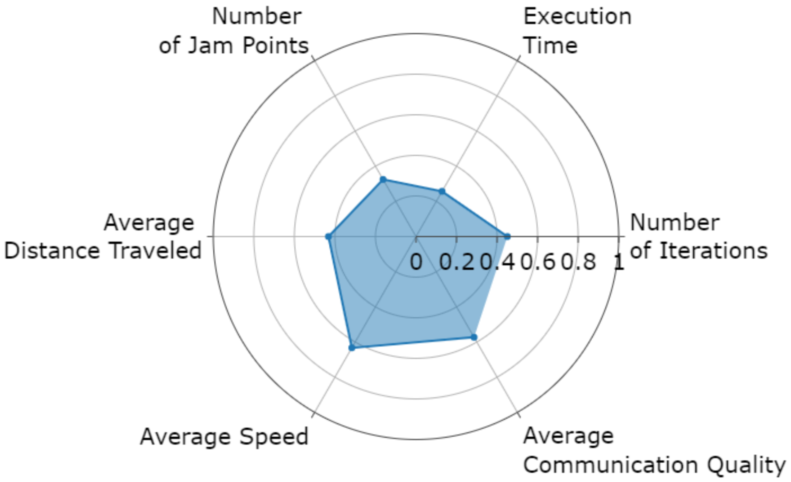
Theta*



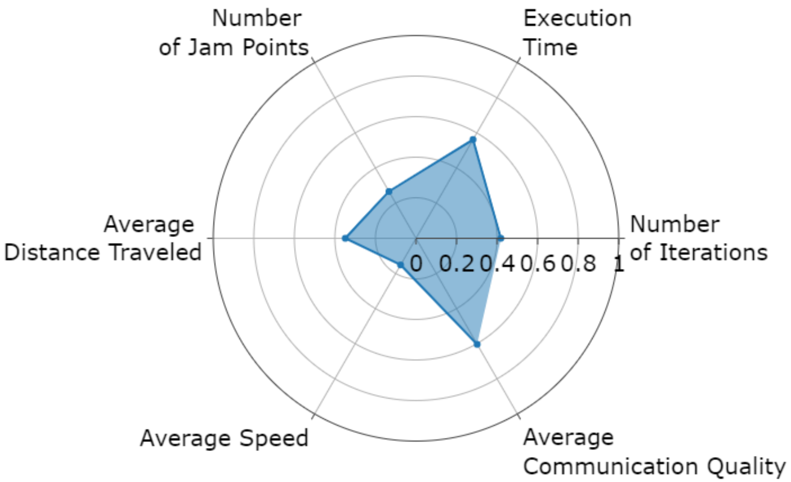
Jump Point Search



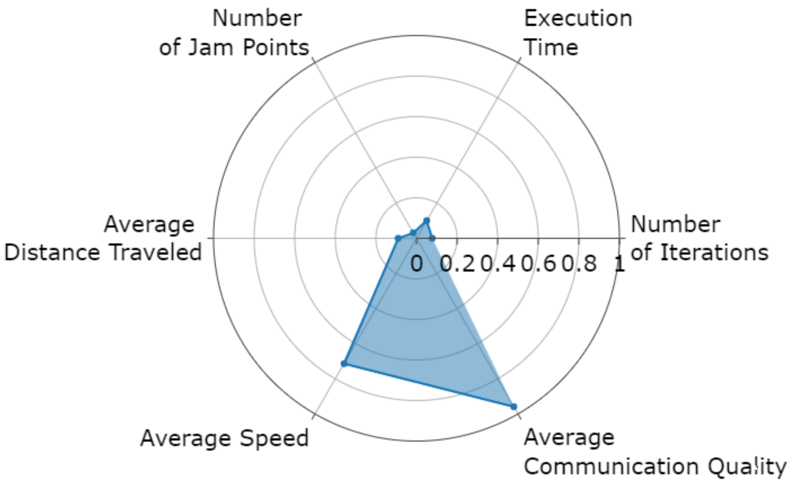
Breadth First Search



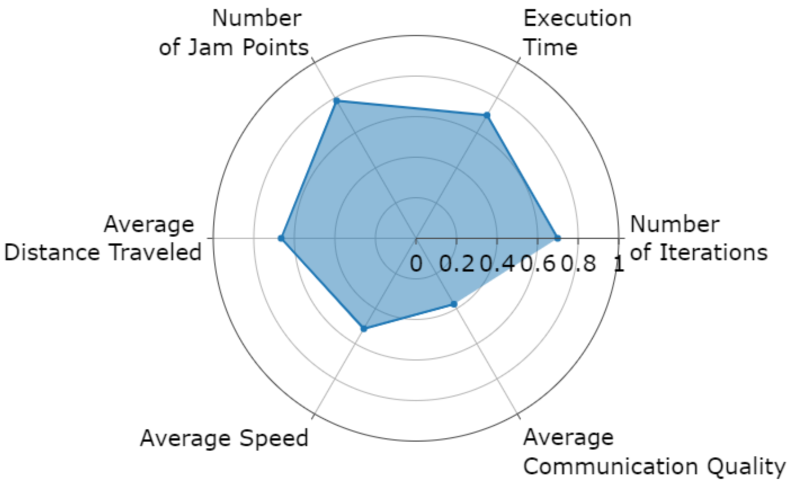
Greedy Best First Search



A*



Dijkstra



05

Conclusion

Result

- A* is identified as the most effective approach.

- Proposed a novel control strategy for swarm navigation in the presence of unknown jamming areas.

- Ensures efficient navigation, formation maintenance, and robust communication through extensive simulations in all 30 simulations.

Acknowledgement

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- We'd like to thank you Dr. Stansbury for considering us into this research program.
- We'd like to thank you Dr. Yang's guidance throughout this research project.

THANKS

Questions?

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