Patrolling with UAV Swarms

Project for the IOT class A.Y. 2022 / 2023

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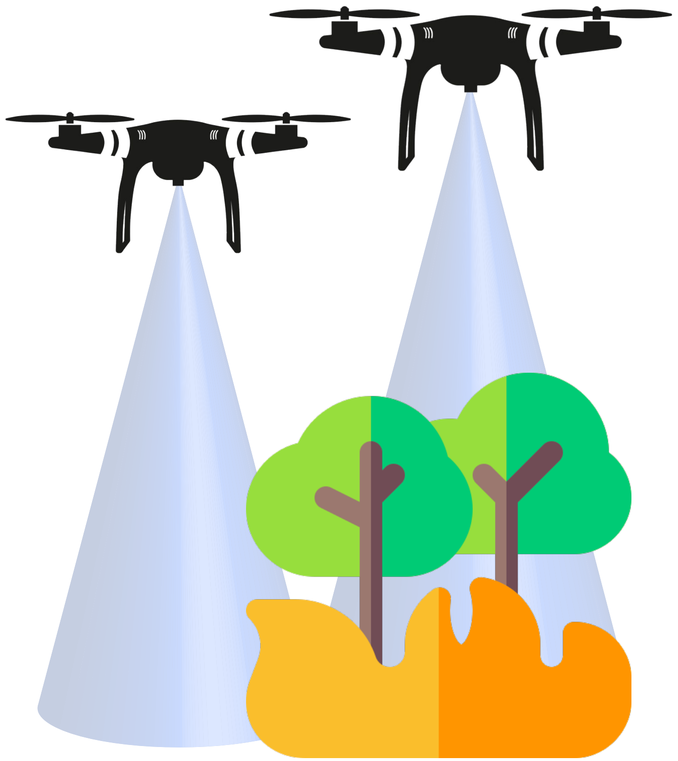
Motivations

❖ Unmanned Aerial Vehicles (UAVs) swarms
- sensors, cellular networking, wireless muti-hop communication
- target detection, classification, tracking, patrolling
- edge server or local base station



❖ Patrolling is the act of **supervising** an area of interest with the intent of keeping the monitored information **as fresh as possible**

- **Intrusion detection**
- **Digital twin update**
- **Environment monitoring**

❖ **Cooperation** of UAVs in a 3D environment

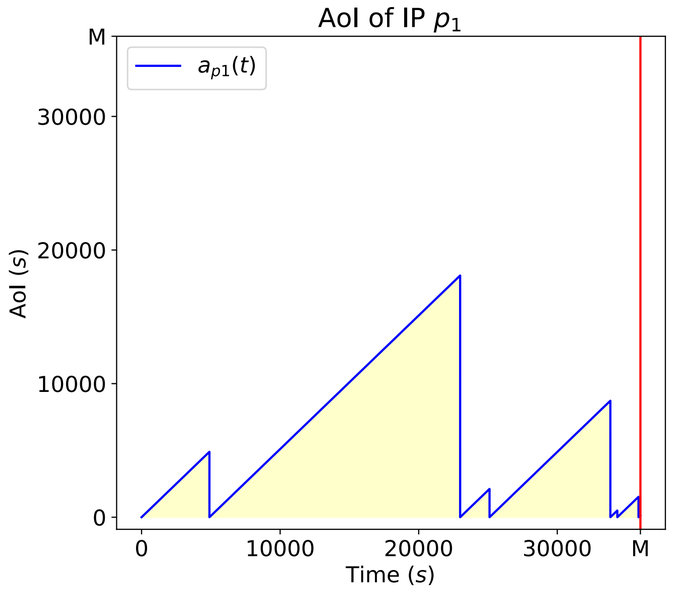
❖ Minimize time between consecutive inspections

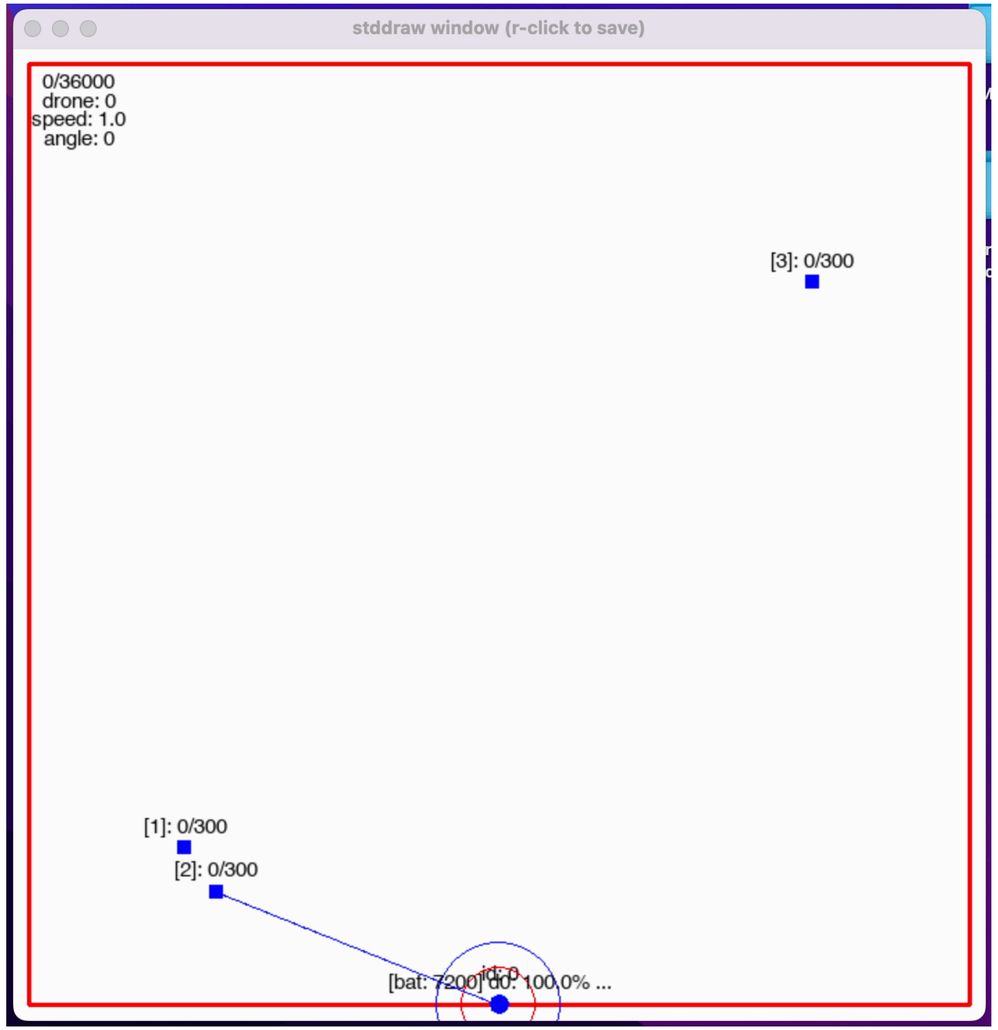
Patrolling Task Overview

- Let $\mathcal{U}$ be the set of **UAVs**, let $\mathcal{I}$ be the set of **inspection points IPs**
- We define a **valid visit** or **inspection** when:

$$d(\dot{p}, \dot{u}) \leq r_s$$

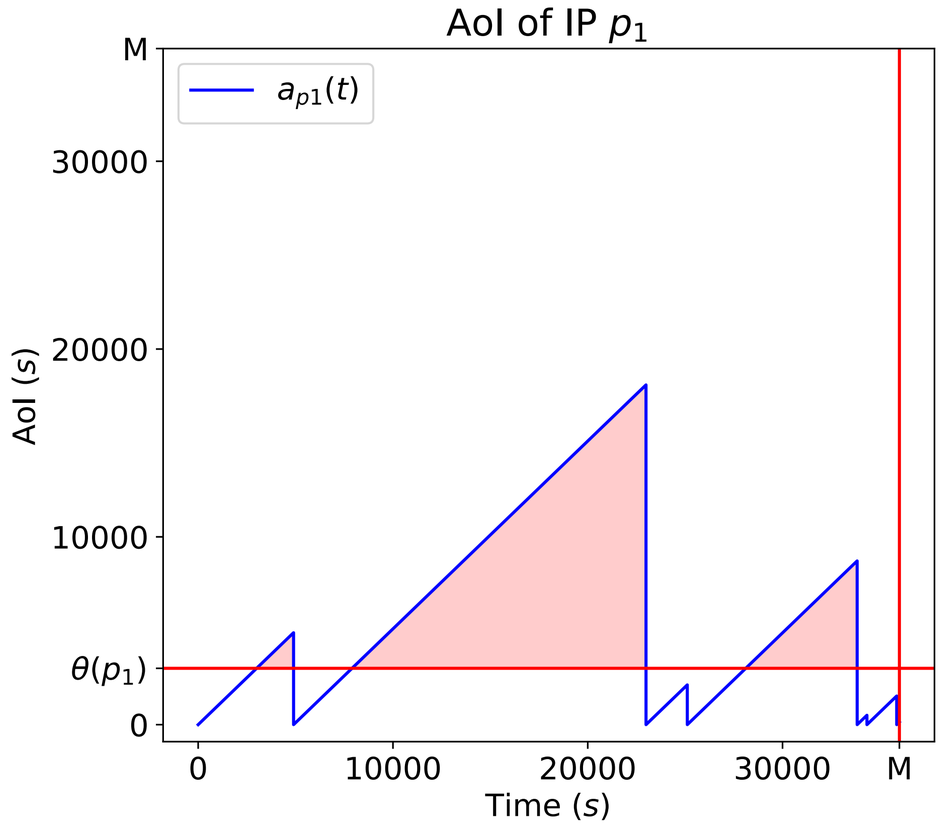
- **Def.** ***age of information*** AoI the function $a_p(t)$ represents the time (seconds) elapsing between two consecutive visits of any UAV to an IP point

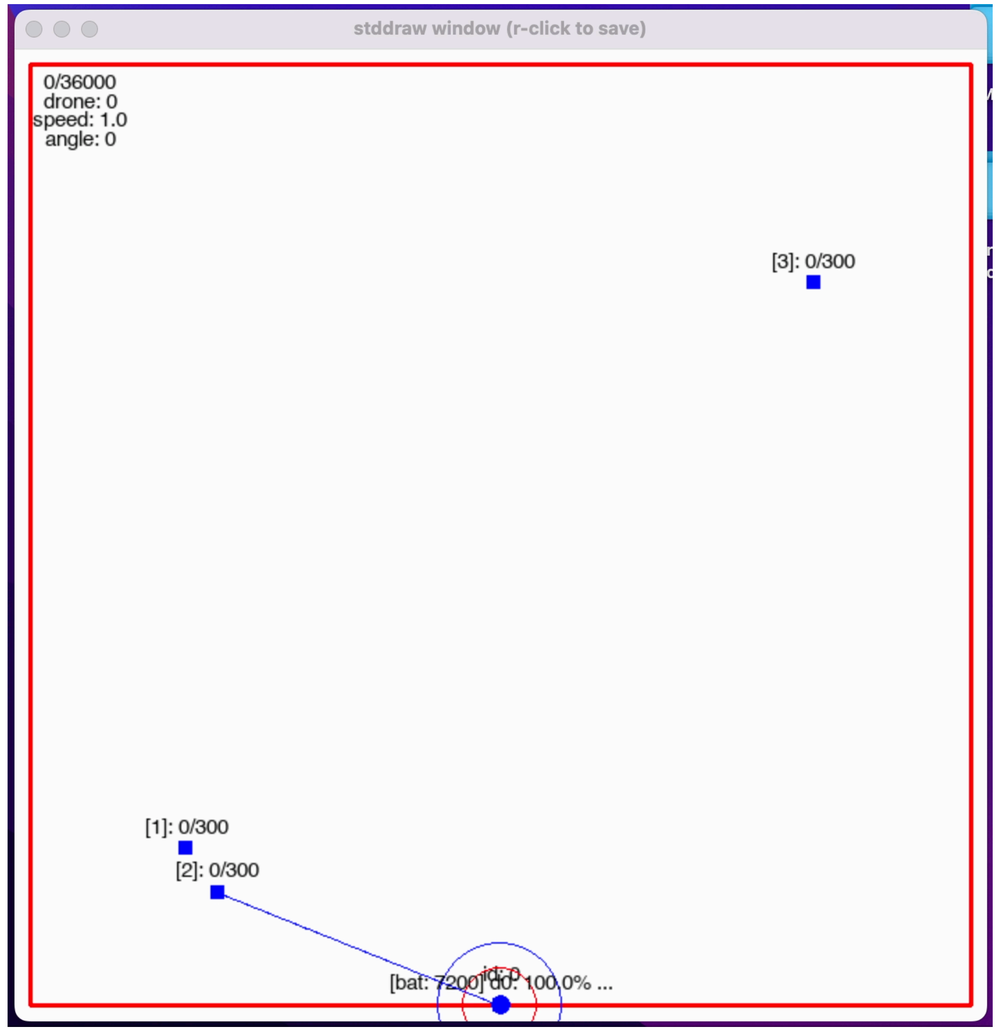




Patrolling Task Overview

❖ **Def. *inter-visit threshold*** $\theta(p)$ represents the AoI (seconds) that the IP *p* can tolerate





Patrolling Performance Metrics Single IP

❖ Optimization criteria for the AoI of a **single** IP *p*

- ***minimize cumulative AoI***

$$c_1(p) : \int_{t=0}^{M} a_p(t)\, dt$$

- ***minimize cumulative time in violation***

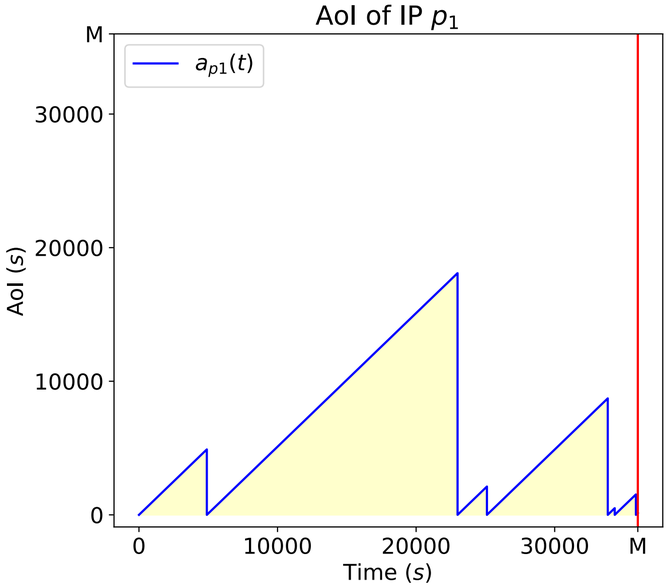
$$c_2(p) : \int_{t=0}^{M} a_p(t) \cdot \rho(a_p(t) > \theta_p)\, dt + \varepsilon \cdot \int_{t=0}^{M} a_p(t)\, dt$$

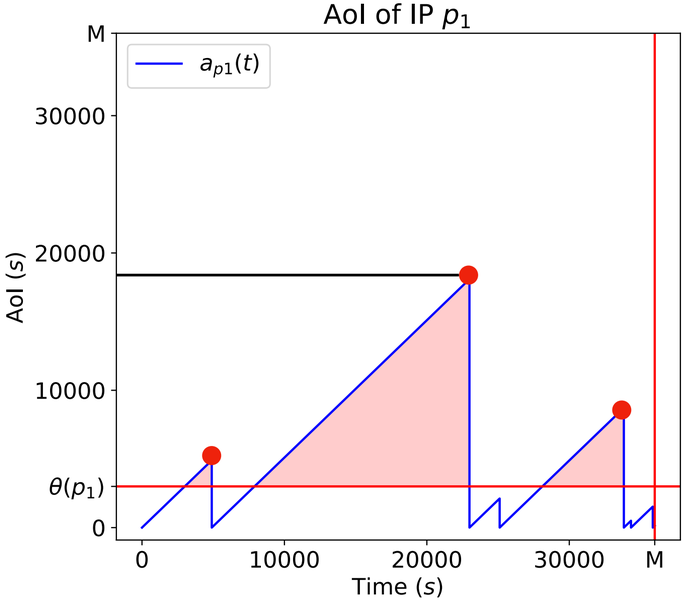
- ***minimize worst AoI***

$$c_3(p) : \max_{0 \le t \le M} a_p(t)$$

- ***minimize number of violations***

$$c_4(p) : \int_{t=0}^{M} \rho(\rho(a_p(t-1) \le \theta_p) \wedge \rho(a_p(t) > \theta_p))\, dt$$





Patrolling Performance Metrics Multiple IPs

❖ Optimization criteria for multiple IPs

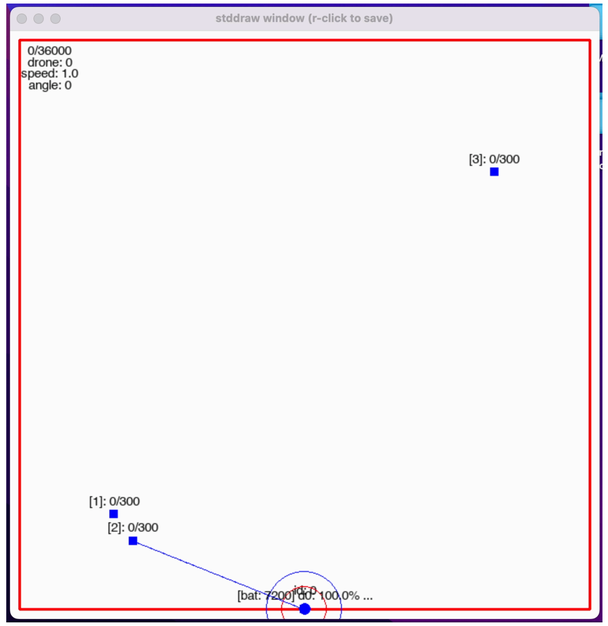
- ***minimize average (****or the sum****) criterion over the IPs***

$$\min \frac{1}{|\mathcal{I}|} \sum_{p \in \mathcal{I}} c_i(p)$$

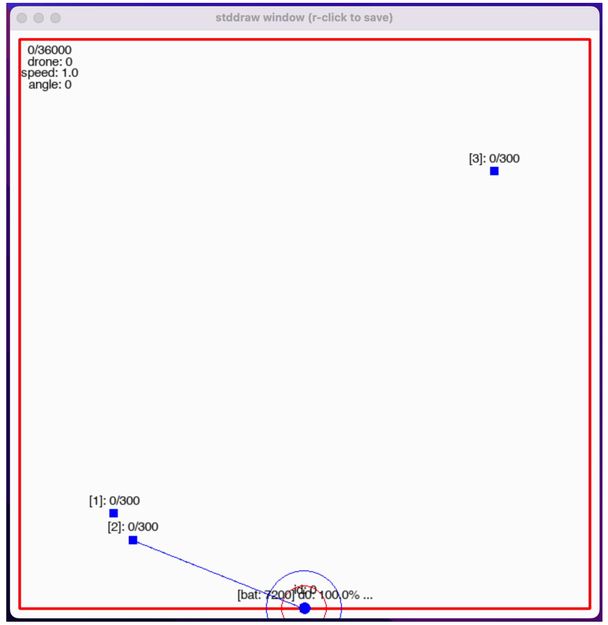
- ***minimize max (****worst****) criterion over the IPs***

$$\min \max_{p \in \mathcal{I}} c_i(p)$$

TSP POLICY



LOOP POLICY



Patrolling Performance Metrics Multiple IPs

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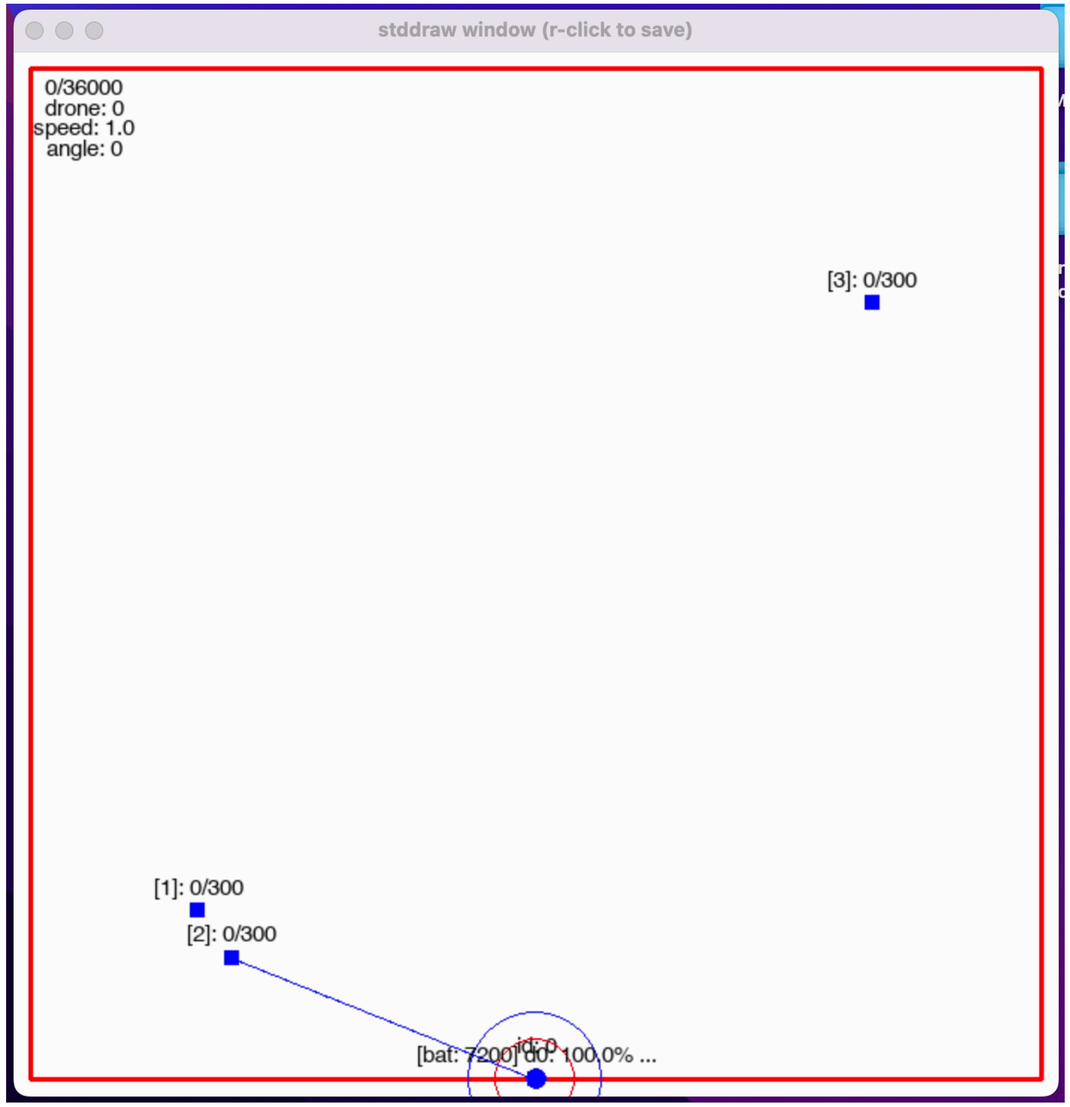

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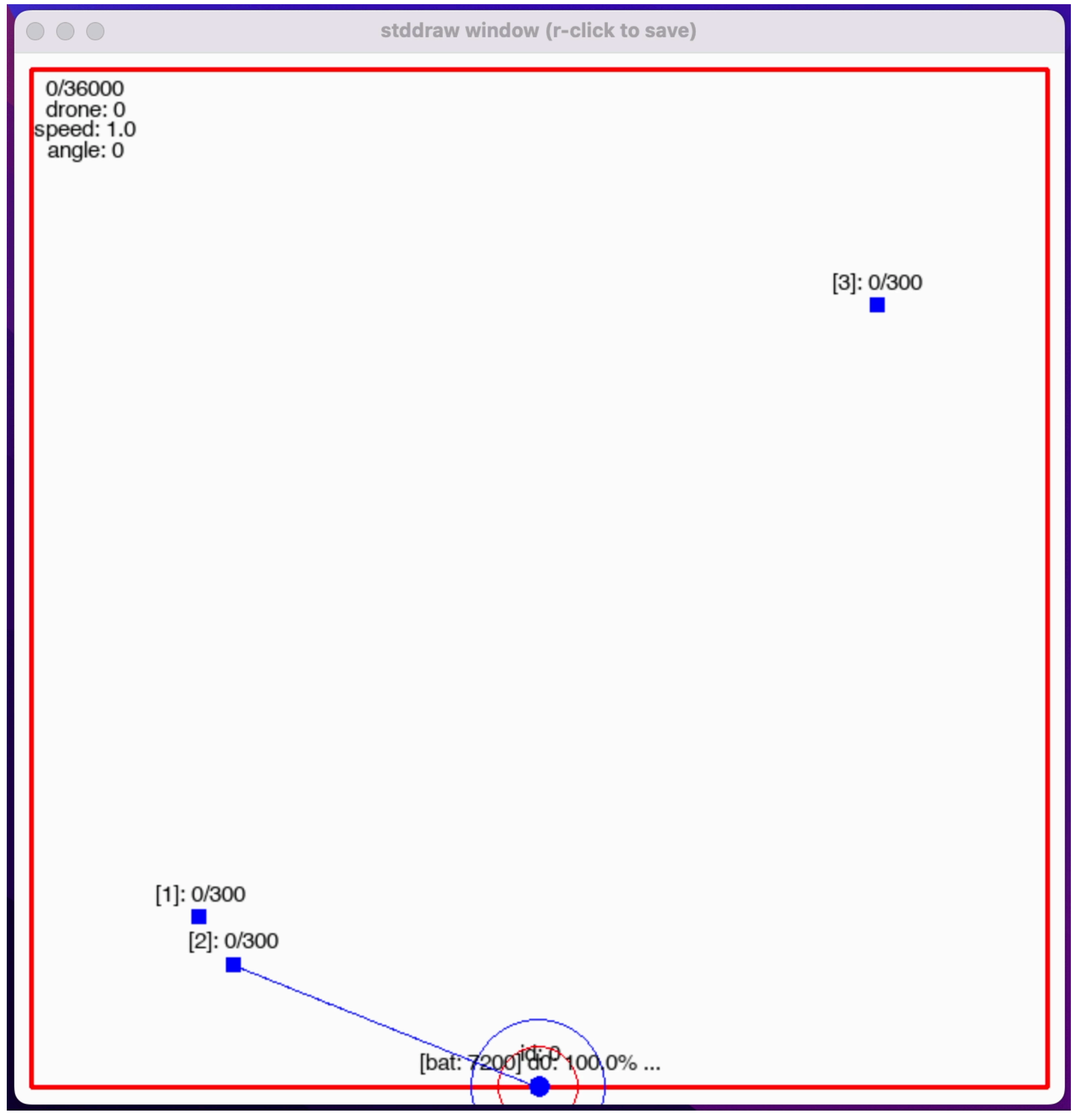


Patrolling Performance Metrics Multiple IPs

❖ Optimization criteria for multiple IPs

- ***minimize average (*** *or the sum* ***) criterion over the IPs***

$$\min \frac{1}{|\mathcal{I}|} \sum_{p \in \mathcal{I}} c_i(p)$$

- ***minimize max (*** *worst* ***) criterion over the IPs***

$$\min \max_{p \in \mathcal{I}} c_i(p)$$

❖ Evaluate the **<u>spread of the distribution</u>** over the targets:

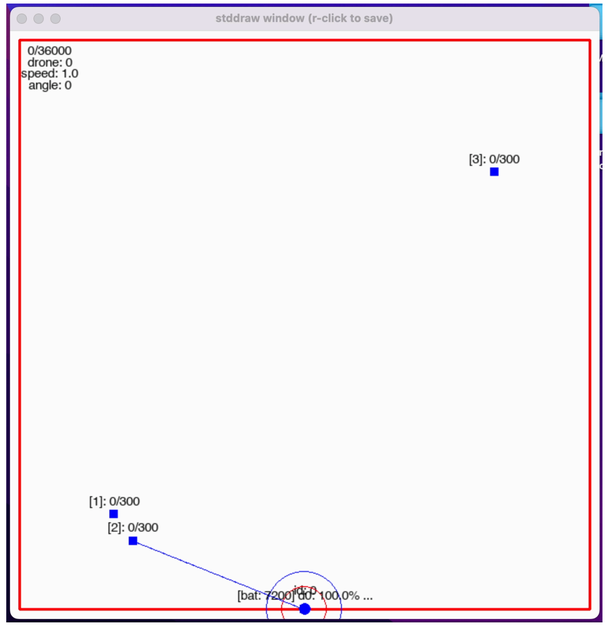
- ***std of the criterion over the IPs***

$$\min \operatorname{std}_{p \in \mathcal{I}} c_i(p)$$

- ***max/min of the criterion over the IPs***

$$\min \max_{p \in \mathcal{I}} c_i(p) - \min_{p \in \mathcal{I}} c_i(p)$$

TSP POLICY



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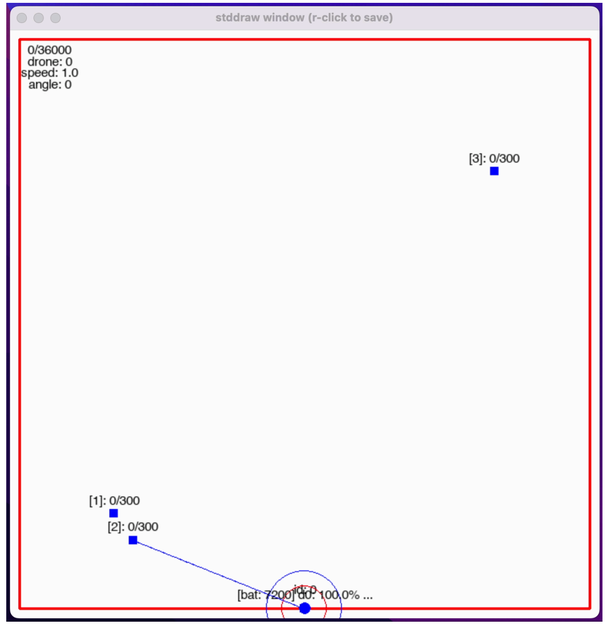
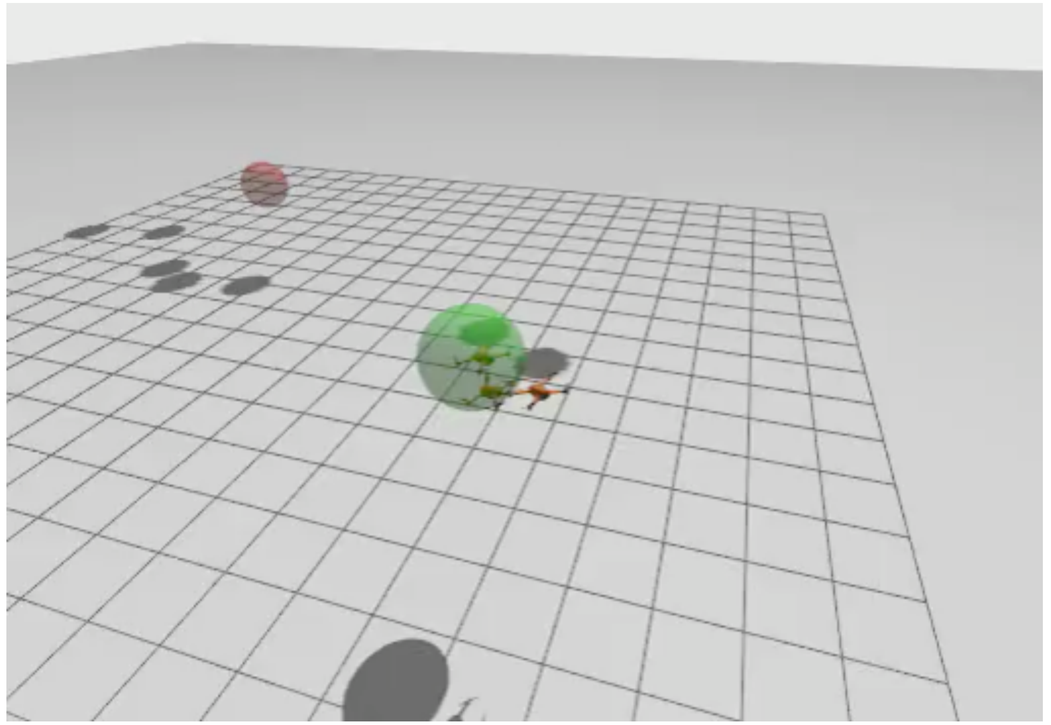


ROS + GAZEBO Simulator

- 12 validation scenarios, varying
  - number of **UAVs**
  - number **target**
  - target **positions**
  - inter-visit **threshold**



SCORE:

$$\frac{1}{|\mathcal{I}|}\sum_{p\in\mathcal{I}}\int_{t=0}^{M} a_p(t)\cdot\rho(a_p(t)>\theta_p)\,dt+\varepsilon\cdot\int_{t=0}^{M} a_p(t)\,dt$$

freshness

$$\max_{p\in\mathcal{I}} c_i(p)-\min_{p\in\mathcal{I}} c_i(p)$$

fairness

Projects Info

- Form groups of up to 3 members
- **Project specs:** GitHub.com/Fede3751/IoT-Project
- Send your solution according to GIT requirements to **trombetti@di.uniroma1.it**
- Deadline: **May 28, 2023 23:59**
- Contest to run the best solutions **LIVE** in class: **May 31, 2023**

The WINNING group will skip the written exam*