Exploring the Benefits of Sharing Energy within Robot Swarm Networks

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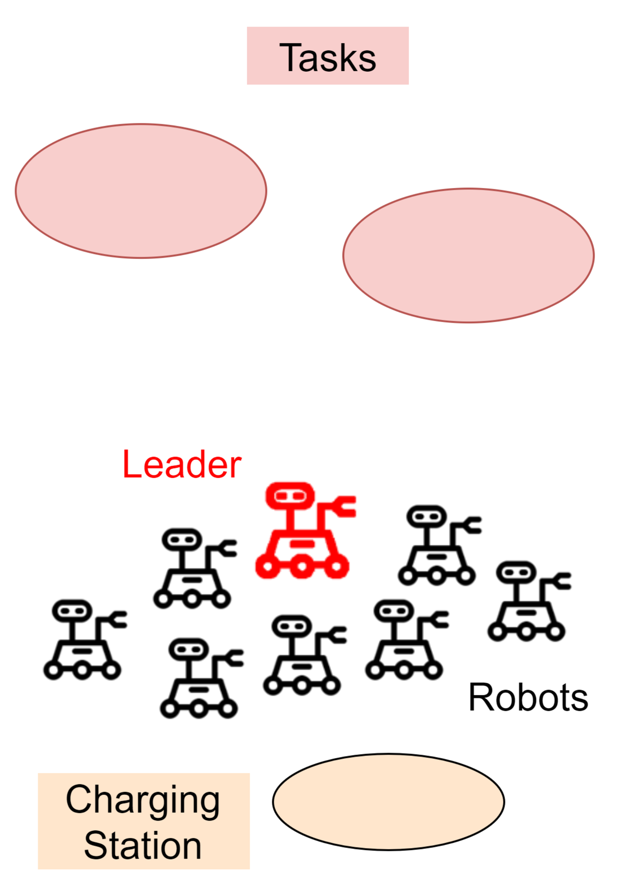
1. Background

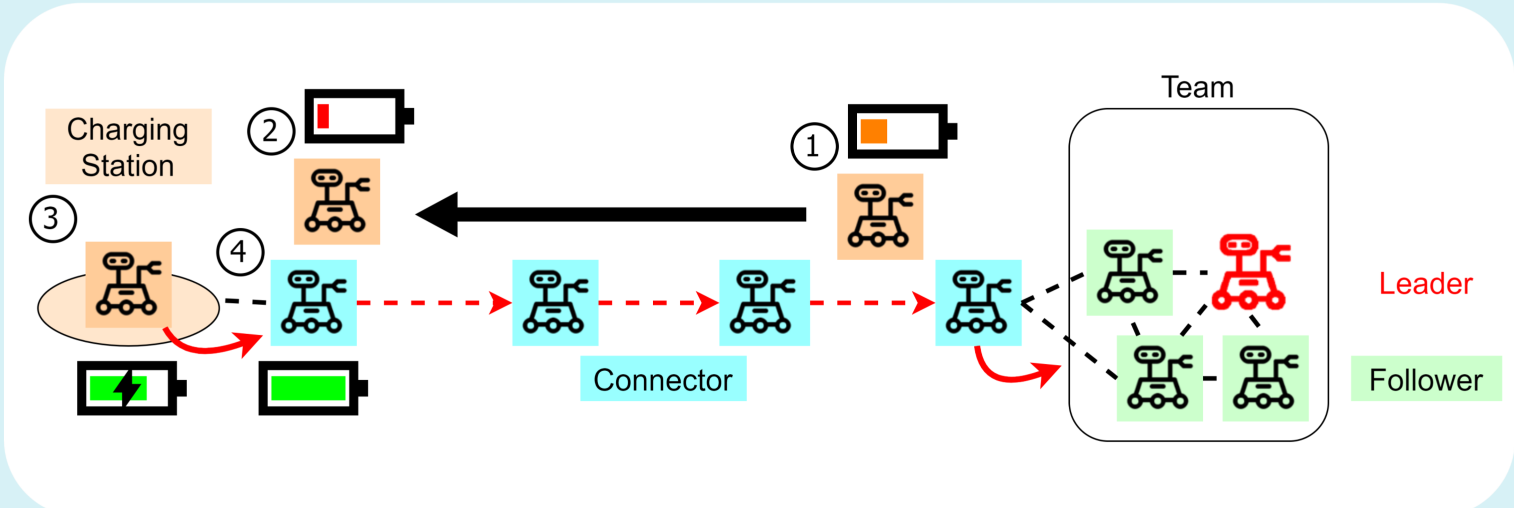
- **Robot swarms** in the real world must be **energy-aware** to perform tasks that may last for extended periods of time, such as surveillance and connectivity maintenance
- **Energy trophallaxis** is the ability of *robots to recharge each other's battery* which may improve swarm to operator longer
- New platforms such as *FreeBot* [1] enable robot-to-robot charging at a duty cycle of 98%
- We investigate the effectiveness of energy trophallaxis for robot swarm networks by identifying conditions in which sharing energy among individual robots becomes most effective

2. Problem

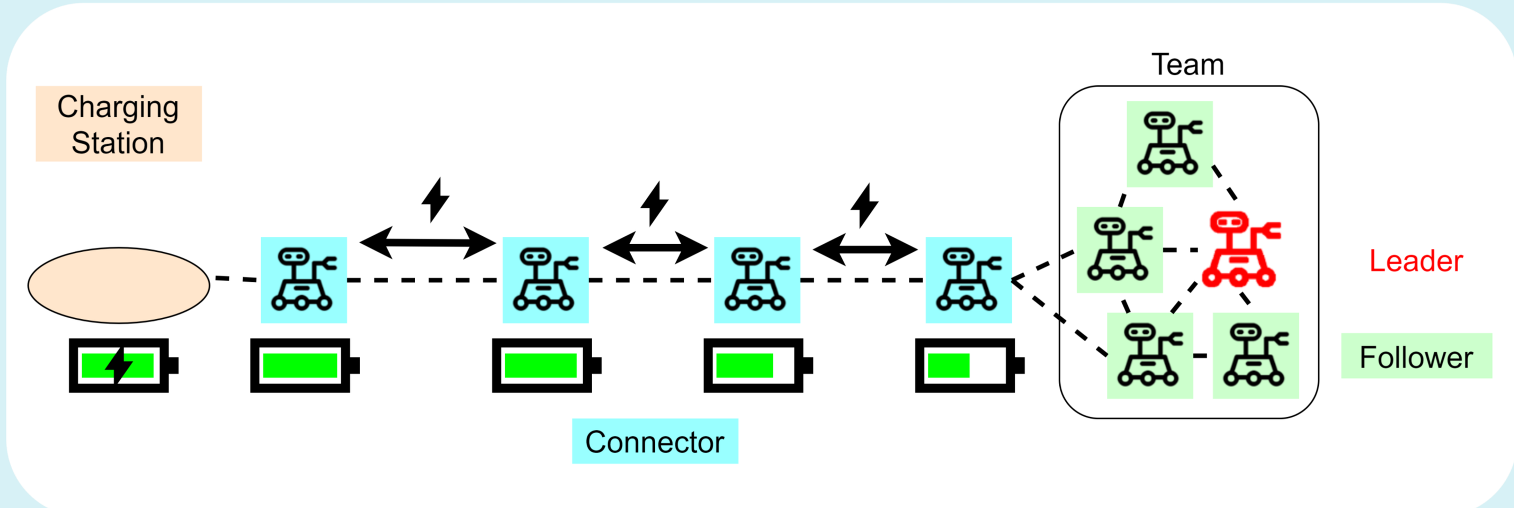


- **Tasks:** Require robots to complete
- **Robots:**
  - Local positioning and communication
  - Consume *energy* when (1) idle, (2) moving or (3) working
  - Can share energy with neighbours
- **Leader:** Guides robots to the tasks
- **Charging Station:** Fully recharges a robot's energy
- **Goal:** Complete all tasks while keeping all robots alive

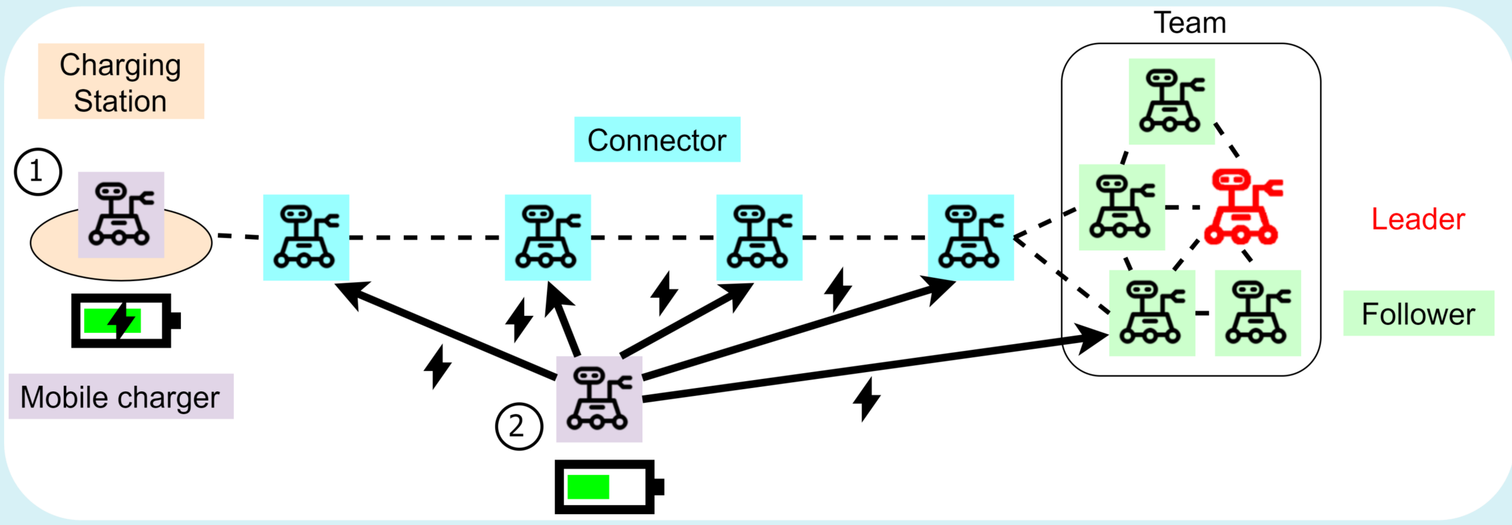
3. Methodology



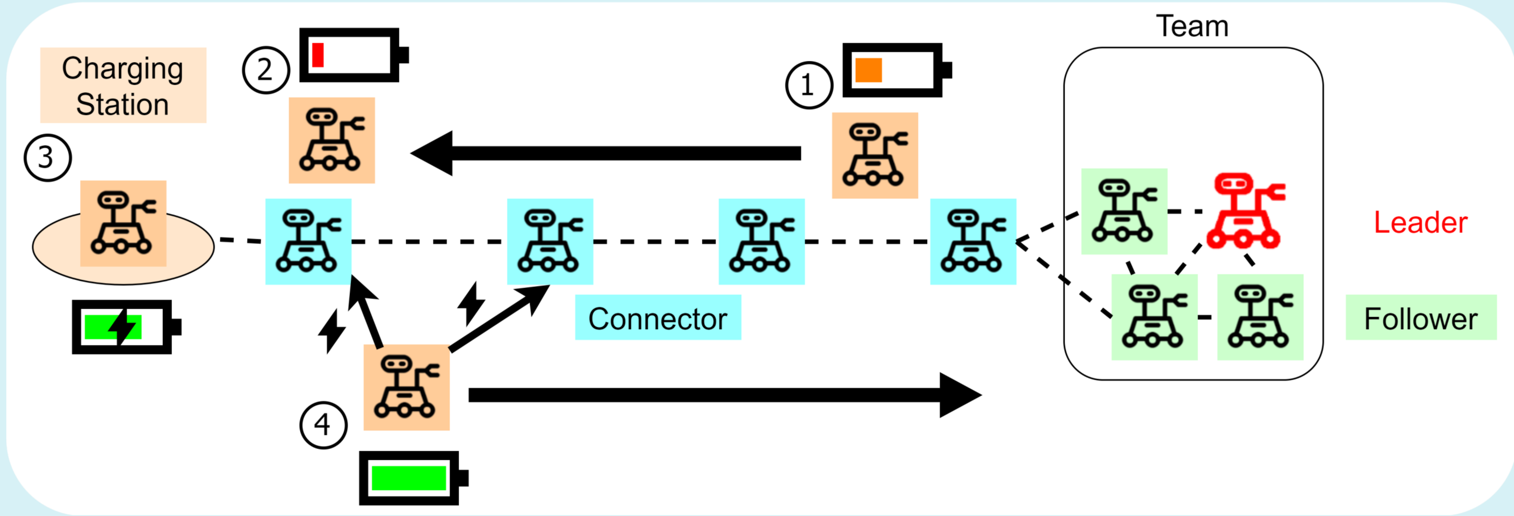
Strategy 1: Shifting the Network *(no energy trophallaxis)*
A robot that is low on energy travels to the charging station. Once fully charged, it adds itself to the network to allow the robot closest to the team to join the team



Strategy 2: Share Energy with Neighbours
Robots share energy with their neighbours in the network, creating a flow of energy from the charging station to the team without any robot having to travel the full length



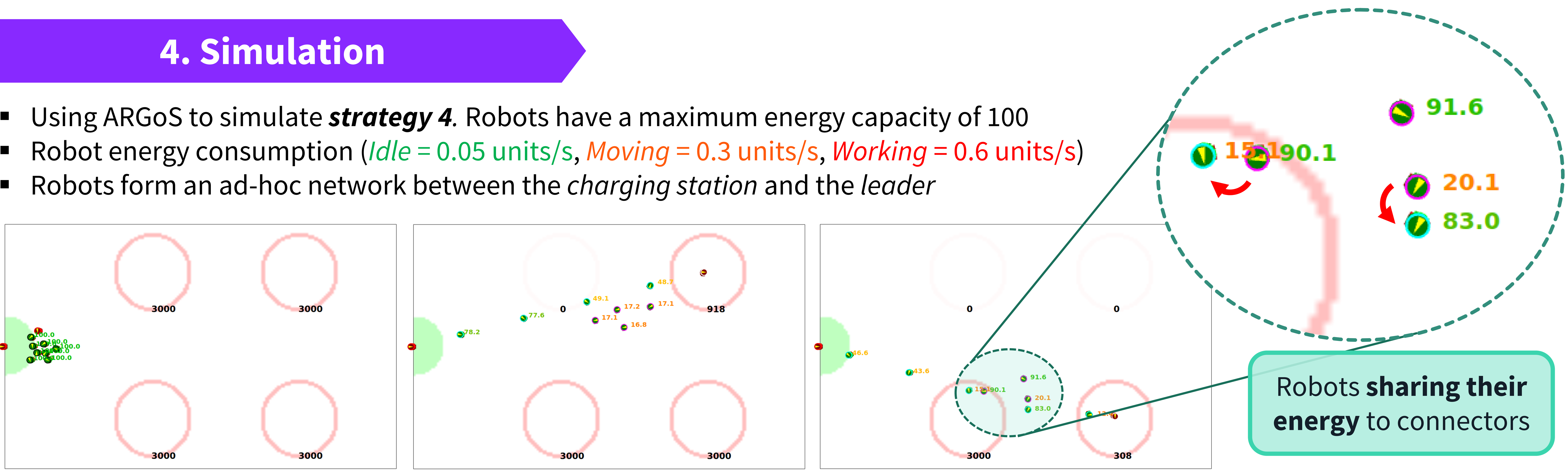
Strategy 3: Share Energy via a Mobile Charger
One or more dedicated robots are assigned the role of mobile charger, which is tasked to keep other robots alive by sharing its own energy



Strategy 4: Share Energy while Returning to the Team
A robot that is low on energy travels to the charging station. Once fully charged, it returns to the team while also sharing energy to any connectors that need to be recharged

4. Simulation

- Using ARGoS to simulate ***strategy 4***. Robots have a maximum energy capacity of 100
- Robot energy consumption (*Idle* = 0.05 units/s, *Moving* = 0.3 units/s, *Working* = 0.6 units/s)
- Robots form an ad-hoc network between the *charging station* and the *leader*



7th IEEE UK & Ireland RAS Conference (RAS 2024)

[1] M. Liu, F. Yang, S. Michiels, T. Van Eyck, D. Hughes, et al., "Demo Abstract: FreeBot, a Battery-Free Swarm Robotics Platform", ACM Conference on Embedded Networked Sensor Systems (SenSys), ACM, 2023.

[2] G. Miyauchi, Y. K. Lopes, R. Groß, "Multi-Operator Control of Connectivity-Preserving Robot Swarms Using Supervisory Control Theory," in 2022 IEEE International Conference on Robotics and Automation (ICRA), 2022, pp. 6889–6895.

* This document is issued within the frame and for the purpose of the OpenSwarm project. This project has received funding from the European Union's Horizon Europe Framework Programme under Grant Agreement No. 101093046. Views and opinions expressed are however those of the author(s) only and the European Commission is not responsible for any use that may be made of the information it contains.