Distributed methods for multi-agent system auto-organisation

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The internship focuses on the self-organisation of a group of agents using distributed methods. The context is a set of robotic sensors/actuators (air, land or sea drones) communicating via a wireless network with a dynamic structure.

1 Background and state of the art

The development of autonomous drone-type robots raises the issue of their ability to operate independently in groups. There are many applications for wireless sensor networks: in handling, surveillance and rescue in environments that are difficult to access or dangerous, in agricultural or industrial production [5]. In the case of robots, in addition to being equipped with sensors, they can act on their environment, which multiplies the number of use cases [6, 1].

Nevertheless, for the group to function autonomously, it must be able to manage not only each agent individually, but also their collaboration within the network. It must therefore be possible to deploy and maintain the communication network between agents dynamically, ensuring that the network structure is well suited to the tasks to be performed and respecting constraints such as communication range [4]. Sensor/actuator networks are most often connected by a network whose structure is constrained either at the physical level (wired communication) or at the logical level (e.g. by assigning leader/follower roles to each agent). We are interested, on the contrary, in the case of unconstrained structures, so that they are able to adapt to the tasks to be performed. Agents may be required to play different roles in the system due to their positioning, but these roles are not fixed a priori.

Another challenge is that this structural adaptation must be carried out in a distributed manner. This is a significant constraint for reasons of both scalability and system robustness. Centralised management of a system with a large number of agents involves too much communication. It also weakens the system by introducing sensitive points whose failure is critical for the entire group. Algorithms have been proposed to reduce the average number of connections per node in a graph in a distributed manner without breaking connectivity using spectral methods [3, 2]. An algorithm has also recently been presented that allows critical edges (i.e. those whose removal would cause the network to disconnect) to be identified in a distributed manner [7].

2 Internship goals

One of the main objectives of the internship would be to develop an algorithm that allows a group of networked agents to choose which communication to abandon, not to reduce the average number of connections per node, but to allow the nodes to change their spatial configuration. Maintaining communication between two agents requires them to remain within range of each other, which limits their ability to move. The critical edge identification algorithm tests whether an edge must be retained to ensure network connectivity. However, even if an edge is not critical, its removal still requires coordination, because if several nodes independently decide to remove communications, the network may become disconnected, even though none of the abandoned edges were critical.

A second objective, complementary to the first, is to develop an algorithm for establishing new communications. This may be to duplicate edges identified as critical, thereby strengthening the robustness of the network, or to enable the removal of a critical edge. However, establishing new communications requires nodes to be within range, and may therefore involve movement: decisions relating to communications between agents and their movements must therefore be linked.

3 Production and perspectives

As part of this project, we have developed a digital environment that allows us to visualise the deployment of mobile agents and changes in their organisation. The work carried out during the internship can therefore be naturally integrated into this environment, allowing us to simulate different situations and test the proposed methods.

In the short term, this environment provides us with an interactive tool that is easy to understand and use, which can be used to present the results of our work both in an academic context and when presenting to a non-scientific audience, at science festivals or during laboratory visits by university or secondary school students.

In the longer term, our aim is to use these methods to improve the resilience of autonomous robot groups (whether terrestrial, aerial or aquatic) and their ability to perform observation or intervention tasks, for example in monitoring hazardous environments (forest fires, polluted areas), rescue operations in areas that are difficult to access, or restoring communications networks after natural disasters.

4 Candidate

This internship is aimed at M2-level computer science students interested in research. The possibility of continuing this work with a thesis may be considered if the candidate is interested, as we are currently applying to find fundings for a thesis on the same topic.

5 Fundings

This project is part of a joint LISTIC/LCIS response to the MIAI 2025-2026 call for chairs on distributed learning within a group of mobile agents, as well as the emergence and learning (adaptation) of organisations within such mobile agent group.

References

[1] Kurt Ahmet, Uluagac A. Selcuk, Kemal Akkaya, and Nico Saputro. Distributed Connectivity Maintenance in Swarm of Drones During Post-Disaster Transportation Applications, 2021.

[2] Made Widhi Surya Atman and Azwirman Gusrialdi. Distributed Algorithms for Verifying and Ensuring Strong Connectivity of Directed Networks. In *2021 60th IEEE Conference on Decision and Control (CDC)*, pages 4798–4803, Austin, TX, USA, December 2021. IEEE.

[3] Azwirman Gusrialdi. Connectivity-preserving distributed algorithms for removing links in directed networks. *Network Science*, 10(3):215–233, September 2022.

[4] Sunan Huang, Wenbing Cui, Jiawei Cao, and Rodney Swee Huat Teo. Self-organizing Formation Control of Multiple Unmanned Aerial Vehicles. In *IECON 2019 - 45th Annual Conference of the IEEE Industrial Electronics Society*, volume 1, pages 5287–5291, October 2019. ISSN: 2577-1647.

[5] Dionisis Kandris, Christos Nakas, Dimitrios Vomvas, and Grigorios Koulouras. Applications of Wireless Sensor Networks: An Up-to-Date Survey. *Applied System Innovation*, 3(1):14, March 2020. Number: 1 Publisher: Multidisciplinary Digital Publishing Institute.

[6] Ban-Sok Shin, Dhruv Patel, Luis Wientgens, Dmitriy Shutin, and Armin Dekorsy. Multi-Agent 3D Seismic Exploration Using Adapt-then-Combine Full Waveform Inversion in a hardware-in-the-loop System. In *ICASSP 2024 - 2024 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, pages 12911–12915, April 2024. ISSN: 2379-190X.

[7] Deepalakshmi Babu Venkateswaran, Zhihua Qu, and Azwirman Gusrialdi. A Distributed Method for Detecting Critical Edges and Increasing Edge Connectivity in Undirected Networks. In *2024 IEEE 63rd Conference on Decision and Control (CDC)*, pages 6951–6956, Milan, Italy, December 2024. IEEE.