Extending Consensus-based Task Allocation Algorithms with Bid Intercession to Foster Mixed-Initiative

Doctoral Consortium

Victor Guillet
DTIS, ONERA, Université de Toulouse
Toulouse, France
victor.guillet@onera.fr

ABSTRACT

Multi-robot systems are increasingly utilized in dynamic and complex environments for tasks ranging from search-and-rescue operations to infrastructure maintenance. However, these systems face significant challenges in task allocation, particularly in balancing autonomy and human oversight. This research investigates critical facets of multi-robot coordination, including mixed-initiative decision-making, robustness, abstraction for improved decision process readability, allocation constraints (temporal dependencies and task ordering), and scalability. By exploring the interplay of these dimensions, this work seeks to develop a unified framework that ensures cohesive task allocation while maintaining system reliability under communication failures. A central contribution is the integration of human intervention to enhance adaptability, leveraging human contextual awareness to address unforeseen challenges. These findings aim to advance both theoretical and practical understanding, paving the way for robust, adaptable multi-robot systems that meet the demands of real-world applications.

CCS CONCEPTS

• **Computing methodologies → Multi-agent systems**; **Cooperation and coordination**; **Robotic planning**.

ACM Reference Format:
Victor Guillet. 2025. Extending Consensus-based Task Allocation Algorithms with Bid Intercession to Foster Mixed-Initiative: Doctoral Consortium. In *Proc. of the 24th International Conference on Autonomous Agents and Multiagent Systems (AAMAS 2025), Detroit, Michigan, USA, May 19 – 23, 2025*, IFAAMAS, 3 pages.

1 INTRODUCTION

Multi-robot systems (MRS) have emerged as promising tools in addressing a wide range of complex and dynamic problems, from search-and-rescue operations in disaster-stricken areas to large-scale infrastructure monitoring and maintenance. Their ability to autonomously perform tasks with precision and efficiency makes them potentially invaluable in environments that are dangerous, unpredictable, or beyond human reach. However, the deployment of MRS in such contexts also presents significant challenges, particularly in the domain of multi-robot task allocation (MRTA).

Proc. of the 24th International Conference on Autonomous Agents and Multiagent Systems (AAMAS 2025), Y. Vorobeychik, S. Das, A. Nowé (eds.), May 19 – 23, 2025, Detroit, Michigan, USA. © 2025 International Foundation for Autonomous Agents and Multiagent Systems (www.ifaamas.org).

The MRTA problem involves assigning a set of tasks to a team of heterogeneous robots in a manner that optimizes performance metrics such as task completion time or resource utilization [2]. While many approaches have been developed to address this issue, achieving an optimal allocation in dynamic and uncertain environments remains an open problem. These challenges are exacerbated by factors such as communication constraints, environmental uncertainty, and the need to integrate human operators into the decision-making loop. Purely autonomous systems often struggle to handle the complexities of real-world scenarios, where contextual knowledge and real-time human judgment can play a crucial role [6, 8].

To address these limitations, this research explores the interplay of key aspects of multi-robot coordination, including mixed-initiative decision-making, robustness to communication failures, abstraction of decision processes, adherence to allocation constraints (e.g., temporal dependencies and task ordering), and scalability to large teams and task sets. A central premise of this work is that human intervention, when judiciously integrated, can significantly enhance the adaptability and reliability of multi-robot systems. By leveraging the strengths of autonomous algorithms for efficient decision-making and the contextual awareness of human operators, this research seeks to propose a unified framework that allows for balancing autonomy with oversight. Particular attention is put on the importance of real-time adaptability, where MRS can dynamically reallocate tasks based on changing environmental conditions, task dependencies, or partial system failure.

2 MIXED INITIATIVE IN DECENTRALISED SYSTEMS

This PhD explores decision-making architectures that balance autonomous operations with human oversight in multi-robot systems (MRS). Achieving this balance is vital in real-world scenarios where fully autonomous systems struggle to adapt to dynamic environments, and human operators provide essential contextual insights. This work emphasizes mixed-initiative control, where humans and autonomous systems collaboratively tackle complex problems by leveraging their respective strengths.

The Consensus-Based Allocation Algorithm (CBAA) and Consensus-Based Bundle Auction (CBBA), two popular and effective decentralised methods for solving the MRTA problem, were chosen as baseline for this work [1]. These algorithms were chosen for their scalability, robustness, and decentralized nature. They leverage local decision-making and peer-to-peer communication to achieve a global consensus on task assignments without requiring a centralized controller (Figure 1). In CBAA, tasks are allocated individually based on agents' bids, with conflicts resolved through an iterative consensus process. CBBA extends this concept by enabling agents to form bundles of tasks, optimizing allocations for sequences of interdependent tasks. Both methods are robust to communication failures, and well-suited for dynamic environments, making them ideal for real-world applications where centralized solutions may be infeasible or prone to single points of failure.

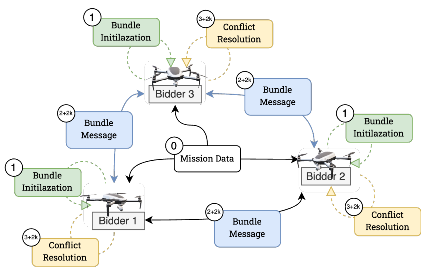

Figure 1: Consensus-based Methods: agents alternate between and auction and a consensus phase to construct plans in parallel (from [7], with permission).

These algorithms however inherently lack the flexibility to incorporate contextual human expertise. The first two papers of this thesis therefore introduce Bid Intercession in Consensus-Based Allocation Algorithms (I-CBAA) [3] and Consensus-Based Bundle Auctions (I-CBBA) [4], enabling human intervention in decentralized task allocation processes. Intercession allows operators to dynamically influence task allocation by overriding or adjusting bids without compromising the system's decentralized structure or robustness. The method is designed to ensure that the system retains the liberty and flexibility to autonomously plan solutions efficiently, while seamlessly integrating additional constraints and influences provided by human operators (Figure 2). This approach maintains the inherent advantages of decentralized systems, such as scalability and fault tolerance, while enhancing adaptability to real-world, dynamic scenarios through contextual human input.

A total of 880 experiments were conducted (88 different configurations over 10 different task schedules), and first evaluations of I-CBBA highlight its ability to address limitations in purely autonomous task allocation, demonstrating improved adaptability to dynamic and uncertain environments. This work establishes a foundation for broader exploration of mixed-initiative systems, focusing on questions of when and why human intervention should occur and how to balance human oversight with system autonomy.

Future works will aim to extend beyond the technical implementation of intercession mechanisms to explore their implications for system design, usability, and ethical considerations. Additionally, the research will investigate how to balance the level of human intervention to avoid over-reliance on operators and maintaining the autonomy of robotic agents. Finally, focus will be put on better understanding and benchmarking the emergent dynamics in the event of communication shortages and failure.

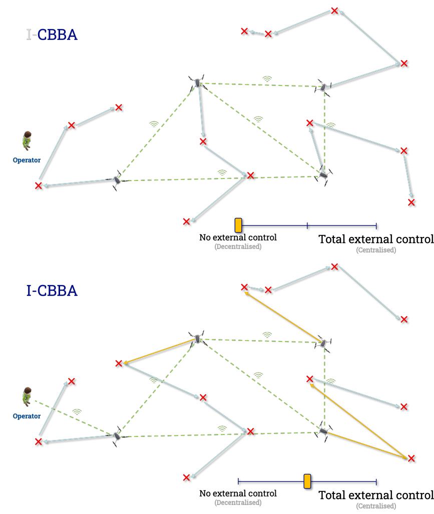

Figure 2: CBBA does not allow for human intervention. Intercession enables partial control of the decision-making process while allowing the algorithm to freely plan with and around human interventions.

3 ALLOCATION PROCESS ABSTRACTION, TRANSPARENCY AND SCALABILITY

While previous work has enabled human intervention in decentralized task allocation, supervising large-scale multi-robot systems remains challenging. The complexity can overwhelm operators, underscoring the need for abstraction to enhance situational awareness and decision-making. Abstraction distills key information, aiding strategic oversight as systems scale. We are currently developing structured decision-making methods for decentralized systems using the MOISE+ framework [5] (Figure 3).

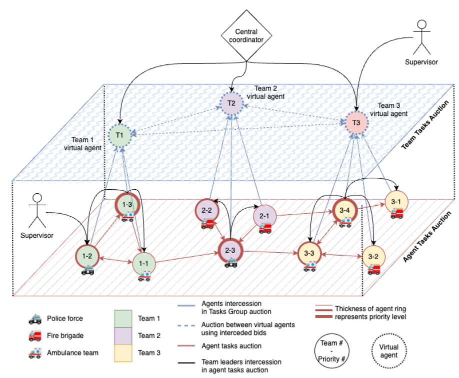

Figure 3: Hierarchized decision-making has the potential to improve both scalability and the operator's oversight and understanding of the system

ACKNOWLEDGMENTS

This work has been funded by the French Ministry of Defence's Innovation Agency (AID).

REFERENCES

[1] Han-Lim Choi, Luc Brunet, and Jonathan P. How. 2009. Consensus-Based Decentralized Auctions for Robust Task Allocation. *IEEE Transactions on Robotics* 25, 4 (2009), 912–926. https://doi.org/10.1109/TRO.2009.2022423

[2] Brian P. Gerkey and Maja J. Matarić. 2004. A Formal Analysis and Taxonomy of Task Allocation in Multi-Robot Systems. *The International Journal of Robotics Research* 23, 9 (2004), 939–954. https://doi.org/10.1177/0278364904045564

[3] Victor Guillet, Christophe Grand, Charles Lesire, and Gauthier Picard. 2024. Bid Intercession to Unlock Human Control in Decentralized Consensus-Based Multi-robot Task Allocation Algorithms. In *Agents and Robots for reliable Engineered Autonomy (AREA), Santiago de Compostela, Spain*. https://doi.org/10.1007/978-3-031-73180-8_7

[4] Victor Guillet, Christophe Grand, Charles Lesire, and Gauthier Picard. 2024. Extending Consensus-based Task Allocation Algorithms with Bid Intercession to Foster Mixed-Initiative. In *24th International Conference on Autonomous Agents and Multiagent Systems, Detroit, USA*.

[5] Jomi F. Hübner, Jaime S. Sichman, and Olivier Boissier. 2002. A Model for the Structural, Functional, and Deontic Specification of Organizations in Multiagent Systems. In *Brazilian Symposium on Artificial Intelligence, Porto de Galinhas/Recife, Brazil*. https://api.semanticscholar.org/CorpusID:7524187

[6] Aaron W. Johnson, Charles M. Oman, Thomas B. Sheridan, and Kevin R. Duda. 2014. Dynamic task allocation in operational systems: Issues, gaps, and recommendations. In *IEEE Aerospace Conference*. IEEE, Big Sky, MT, USA, 1–15. https://doi.org/10.1109/aero.2014.6836205

[7] Félix Quinton, Christophe Grand, and Charles Lesire. 2023. Market Approaches to the Multi-Robot Task Allocation Problem: a Survey. *Journal of Intelligent and Robotic Systems* 107, 2 (2023), 31. https://doi.org/10.1007/s10846-022-01803-0

[8] Sarvapali D. Ramchurn, Trung Dong Huynh, Feng Wu, Yuki Ikuno, Jack Flann, Luc Moreau, Joel E. Fischer, Wenchao Jiang, Tom Rodden, Edwin Simpson, Steven Reece, Stephen Roberts, and Nicholas R. Jennings. 2016. A disaster response system based on human-agent collectives. *Journal of Artificial Intelligence Research* 57, 1 (9 2016), 661–708.