Chapter 8
Applications of DEC-MDPs in Multi-Robot Systems

Aurélie Beynier
University Pierre and Marie Curie, France

Abdel-Illah Mouaddib
University of Caen, France

ABSTRACT

Optimizing the operation of cooperative multi-robot systems that can cooperatively act in large and complex environments has become an important focal area of research. This issue is motivated by many applications involving a set of cooperative robots that have to decide in a decentralized way how to execute a large set of tasks in partially observable and uncertain environments. Such decision problems are encountered while developing exploration rovers, teams of patrolling robots, rescue-robot colonies, mine-clearance robots, et cetera.

In this chapter, we introduce problematics related to the decentralized control of multi-robot systems. We first describe some applicative domains and review the main characteristics of the decision problems the robots must deal with. Then, we review some existing approaches to solve problems of multiagent decentralized control in stochastic environments. We present the Decentralized Markov Decision Processes and discuss their applicability to real-world multi-robot applications. Then, we introduce OC-DEC-MDPs and 2V-DEC-MDPs which have been developed to increase the applicability of DEC-MDPs.

INTRODUCTION

Recent robotic researches have demonstrated the feasibility of projects such as space exploration by mobile robots, mine clearance of risky area, search and rescue of civilians in urban disaster environments, etc. In order to increase the performance and abilities of these robots, researchers aim at developing multi-robot systems where the robots could interact. As explained by Estlin et al. (Estlin et al., 1999) about multi-rover exploration of Mars, such teams of robots will be able to collect more data by dividing tasks among the robots. More complex tasks that require several robots to cooperate, could also be executed. Moreover, abilities of the team could be improved by enabling

DOI: 10.4018/978-1-4666-4607-0.ch008

each rover to have special skills. Finally, if one robot fails (robot breakdown or failure of task execution), another robot will be able to repair the damage to the first robot or will complete the unexecuted tasks. Teams of robots can also be used to increase the efficiency of rescue robots, patrolling robots or to develop constellations of satellites (Damiani et al., 2005). All these applications share common characteristics: they are composed of a set of robots that must autonomously and cooperatively act in uncertain and partially observable environments. Thus, each robot must be able to decide on its own, how to act so as to maximize the global performance of the system. In order these robots to be able to optimize their behaviors, decision making approaches that take into account characteristics of real-world applications (large systems, constraints on task execution, uncertainty and partial observability) have then to be developed.

Markov Decision Processes (MDPs) and Partially Observable Markov Decision Processes (POMDPs) have proved to be efficient tools for solving problems of single-agent control in stochastic environments (Puterman, 2005, Kaelbling et al., 1998, Zilberstein et al., 2002). The application of MDPs has therefore been extended to multiagent settings. Thus, Decentralized Markov Decision Processes (DEC-MDPs) have been proposed (Bernstein et al., 2002). They allow for modeling cooperative and distributed decision problems under uncertainty and partial observability. This chapter will describe how DEC-MDP approaches can contribute to solve multi-robot decision problems.

The chapter will be divided into three main parts. The first part will describe multi-robot real-world applications and we will introduce problematics related to the decentralized control of robot teams. The second part will introduce the DEC-MDP framework and the last part of the chapter will present existing DEC-MDP approaches that are concerned with solving multi-robot decision problems.

DECENTRALIZED CONTROL IN MULTI-ROBOT SYSTEMS

This section introduces problematics related to the decentralized control of multi-robot systems. Optimizing the operation of cooperative multi-robot systems that can cooperatively act in large and complex environments has become an important focal area of research. This issue is motivated by many applications involving a set of cooperative robots that have to decide in a decentralized way how to execute a large set of tasks in partially observable and uncertain environments.

Mars Exploration Scenario

The first problem we consider consists in controlling task execution of a cooperative team of Mars exploration rovers. Once a day, the team receives, from a ground center, a set of tasks to execute (observations, measurements, moves) which is intended to increase science knowledge. As the amount of useful scientific data returned to the ground measures the success of the mission, rovers aim at maximizing science return. This performance measure can be represented by an expected value function. In order to optimize this function, several kinds of constraints must be respected while executing the tasks (Cardon et al., 2001, Bresina et al., 2002, Zilberstein et al., 2002):

- **Temporal Constraints:** start times and end times of tasks have to respect temporal constraints. Since robots are solar-powered, most operations must be executed during the day. Moreover, because of illumination constraints, pictures must be taken at sunset or sunrise. On the other hand, some operations must be performed at night (atmospheric measurements).
- **Preconditions:** Some tasks have setup conditions that must hold before they can be performed. For instance, instruments must be turned on and calibrated in or-

Related Content

Aerial Robot Formation Control via Pigeon-Inspired Optimization
Haibin Duan (2016). *Handbook of Research on Design, Control, and Modeling of Swarm Robotics (pp. 83-114).*
www.irma-international.org/chapter/aerial-robot-formation-control-via-pigeon-inspired-optimization/141996

Reconfiguration of Autonomous Robotics
Yujian Fuand Steven Drager (2015). *International Journal of Robotics Applications and Technologies (pp. 41-58).*
www.irma-international.org/article/reconfiguration-of-autonomous-robotics/134033

Prediction of Grape Fruit Disease Using Shuffled Frog Leaping Algorithm-Based Convolutional Neural Network
Gokula Krishnan V., Deepa J., Pinagadi Venkateswara Rao, K. Sreerama Murthy, Hemamalini S.and Avula Chitty (2023). *Applying Drone Technologies and Robotics for Agricultural Sustainability (pp. 82-94).*
www.irma-international.org/chapter/prediction-of-grape-fruit-disease-using-shuffled-frog-leaping-algorithm-based-convolutional-neural-network/317066

Coordinating Massive Robot Swarms
Bruce J. MacLennan (2014). *International Journal of Robotics Applications and Technologies (pp. 1-19).*
www.irma-international.org/article/coordinating-massive-robot-swarms/132540

An Empirical Study of the Effect of Parameter Combination on the Performance of Genetic Algorithms
Pi-Sheng Deng (2013). *International Journal of Robotics Applications and Technologies (pp. 43-55).*
www.irma-international.org/article/an-empirical-study-of-the-effect-of-parameter-combination-on-the-performance-of-genetic-algorithms/102469