Decentralized Multi-agent Coordination under MITL Tasks and Communication Constraints

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ABSTRACT

We propose a decentralized framework to solve a coordination problem for multi-agent systems consisting of heterogeneous agents, each of which uses only local information based on limited sensing and communication capabilities. In the proposed method, slower heavy-duty robots are each assigned a task specification specified in metric interval temporal logic. These specifications express complex, time-bounded tasks that are potentially dependent on other agents' actions. Heavy-duty robots update their task plans upon receiving a cooperative request from other heavy-duty robots in order to complete cooperative tasks. These requests are transmitted by the more agile light-duty robots responsible for information exchange, which systematically pursue heavy-duty robots.

Our work in progress aims to present the framework together with a set of assumptions under which the solution is complete. We also aim to evaluate the framework on a series of use cases motivated by search and rescue.

KEYWORDS

Decentralized Coordination, Metric Interval Temporal Logic, Communication Constraints, Heterogeneous Multi-robot System

1 INTRODUCTION AND MOTIVATION

Teams of autonomous robots have been able to perform increasingly complex tasks in controlled environments. In recent years, we have seen increasing efforts to utilize them in uncontrolled environments, for instance to assist in search and rescue at disaster sites. Such extreme environments bring new challenges and force us to relax a number of simplifying assumptions we often pose when addressing multi-agent coordination and planning under complex tasks [1, 2]. For instance, communication network might have failed and the robots cannot communicate with a central node or with each other unless they are in close proximity. In this work we focus on coordination of a team of robots of two types: heavy-duty robots are each asked to accomplish a complex, time-bounded task, possibly requiring occasional collaboration with others. An example of such task could be cleaning debris and collecting local image/audio information. In contrast, agile light-duty robots are used to substitute the missing communication network and fast monitoring of the site. Temporal logics have become a popular means to express desired complex tasks and constraints on agents' behavior. Linear temporal logic (LTL) is often used as a qualitative specification language for expressing high-level tasks [1, 2]. However, LTL cannot specify quantitative time bounds for tasks. To describe tasks and behavior constraints of agents in this work, we use Metric Interval Temporal Logic (MITL) [3], which offers a rigorous, yet relatively user-friendly way to specify a rich set of various complex requirements and dependencies, including explicit time constraints.

A number of previous works focused on distributed or decentralized coordination, planning, and/or control of multi-agent systems from temporal logic specifications. For example, non-cooperative temporal logic tasks are of focus in [1, 4]. Complex cooperative MITL tasks can be achieved with the help of centralized abstraction technique [5–7]. Work in [2] achieve decentralized multi-agent coordination, however without explicit time constraints. On the other hand, coordination of a multi-agent system with limited communication capabilities and global task specification without explicit time constraints are of focus in [8].

Our work in progress aims to address heterogeneous multi-agent coordination to guarantee satisfaction of MITL formulas under communication constraints. The main idea is to (i) propose pursuit-evasion algorithms for the light-duty robot that guarantee information exchange between the heavy-duty robots, and (ii) for each heavy-duty robot, distill cooperation requests in MITL to be communicated to the other heavy-duty robots. Our work also focuses on formulating assumptions under which the information exchange is sufficiently fast to allow for all MITL specifications to be accomplished.

2 PROBLEM AND APPROACH

Consider N heavy-duty robots $\mathcal{R}_H := \{R_{Hi} : i \in \mathcal{N} = \{1, \ldots, N\}\}$ and one light-duty robot R_L, each of which is associated with a distinct radius, within which it can sense and communicate. A set of atomic propositions is assumed to be divided between heavy-duty robots, i.e. $AP = AP_1 \uplus \ldots \uplus AP_N$. Each $R_{Hi} \in \mathcal{R}_H$, $i \in \mathcal{N}$ is modelled as a Weighted Transition System (WTS) $\mathcal{T}_i$ labelled with atomic propositions AP_i. Each heavy-duty robot is assigned an MITL task specification $\varphi_1, \ldots, \varphi_N$ defined over AP that is possibly dependent on actions of the other robots. We aim to find strategies, i.e. sequence of actions in the WTS for the heavy-duty robots, motion plan for the light-duty robot, and information that needs to be exchanged, such that all specifications can be fulfilled. To facilitate this, we translate the MITL specifications into timed automata.

Our approach is illustrated in Figure 1. It consists of two modules. In the first module, the light-duty robot locates the heavy-duty robots within their assigned task region and exchanges cooperative task requests between them. In the second module, each heavy-duty robot synthesizes a feasible plan based on the assigned task

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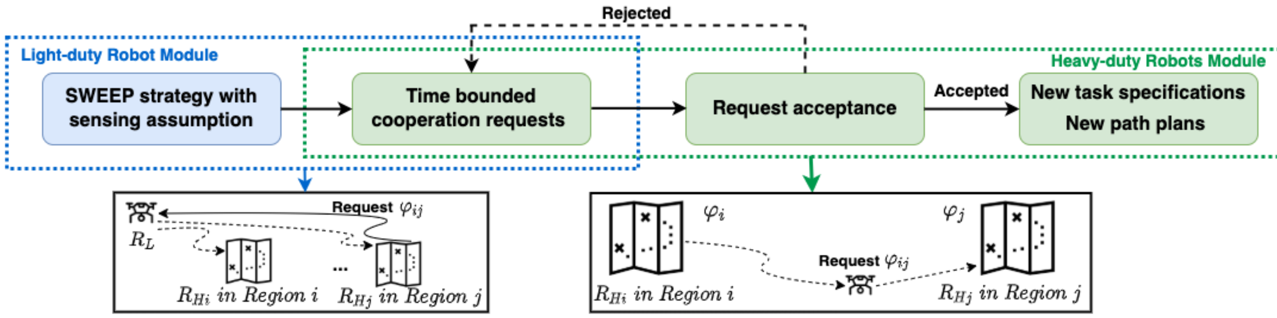

Figure 1: Overall structure of the proposed framework.

specification, as well as requests to be communicated to the other agents; and updates it when receiving requests.

2.1 Light-duty Robot Module

The module in the left outlined by the blue dashed line is concerned with the light-duty robot R_L and the exchange of requests. The light-duty robot deploys a SWEEP strategy [9] with a serpentine pattern, which is preferably used to search large unknown areas without any information about the likely target position. It sequentially pursues the heavy-duty robots and retrieves and transmits the cooperation requests between them. To ensure that the SWEEP strategy of R_L can locate the heavy-duty robots sufficiently fast, we introduce assumptions on the relation between the sensing radius of the light-duty robot and the movement speeds of both agent types. As a result of these assumptions, we can formulate a maximum time bound within which the exchange of requests is guaranteed.

2.2 Heavy-duty Robot Module

The module outlined by the green dashed line is concerned with formulating cooperation requests in MITL and incorporating exchanged requests into the plans of the heavy-duty robots. Each heavy-duty robot R_{Hi} first attempts to generate an initial strategy that satisfies their specification φ_i. If the agent is dependent on other agents through their specification, it also generates requests for the other agents. These requests are stored to be exchanged by the light-duty robot once it arrives. We work on formulating sufficient assumptions on the time bounds of these requests that will yield guarantees on timely exchange of all requests.

When a heavy-duty robot R_{Hj} receives a request φ_{ij}, it either accepts it if a path provably satisfying its own specification and the requests can be synthesized, or rejects it otherwise. The rejected requests are asked to be revised by the agents, who sent them. Convergence criteria for this procedure is one of our current areas of focus.

3 FUTURE WORK

In this ongoing work, we propose a decentralized approach to multi-agent coordination motivated by search and rescue scenarios under time-bounded specifications and limited sensing and communication. Through formulating assumptions on the relation between the sensing radius, motion speed of the agents, time bounds in the specifications, and parameters of the pursuit strategy of the light-duty robot, we aim to guarantee soundness and completeness of our approach.

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