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Yasin Alhamwy

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Yasin Alhamwy

alhamwy@vs.uni-kassel.de
School of Electrical and Computer Engineering
Distributed Systems Research Group
University of Kassel, Kassel, Germany

Abstract: Multi-Agent Systems (MAS) are becoming increasingly popular in large-scale dynamic domains such as Smart Cities and Search & Rescue (S&R) missions. In order for agents to cooperate efficiently in such domains, they need to distribute tasks, share knowledge, resolve conflicts, incorporate unknown agents, assign roles among each other, assign and keep track of teams of agents, etc. The cooperation in such dynamic domains requires both a software platform that supports the interoperability of cyber-physical agents as well as a shared Knowledge Base that stores general semantic information about the entities of discourse as well as live status information. ALICA, which is an in-house Multi-Agent platform, addresses such domains and is well suited to tackle a lot of these problems. To further enhance its capabilities, an extension is planned in order to integrate the standardised context information interface NGSI-LD as well as the widely used FIWARE models and components for Smart Cities, which enables the management of static and dynamic context information in normal and crisis situations.

Keywords: Robotic teams, Multi-Agent Systems, Knowledge Base, Smart Cities

1 Introduction

State of the art robots are able to solve complex problems like warehouse management [ADR19] or preparing breakfast [BKK⁺11]. However, they are limited in their computational power and in regards to the number of sensors they have (lidars, cameras, radar, etc.). There are problems which cannot be achieved by a single robot due to tasks being distributed in time, space or functionality, or it is more efficient, reliable and cost effective to use Multi-Agent Systems (MAS) [RDC05]. The agents may be robots, computer programs (software agents) or even people. The use of MAS is becoming increasingly popular in large-scale dynamic domains like Smart Cities and Search & Rescue missions (S&R). These domains are very dynamic and in order for the agents in them to cooperate efficiently and quickly, the agents need to distribute tasks, share knowledge, resolve conflicts, incorporate unknown agents, assign roles among each other, assign and keep track of teams of agents, etc [OJJG19]. This requires both a software platform that supports the interoperability of cyber-physical agents as well as a shared Knowledge Base that stores general semantic information about the entities of discourse as well as live status information. The ALICA framework addresses such domains and provides dynamic solutions to the aforementioned problems and it has already been used in domains such as space exploration, robotic soccer, and autonomous driving [OJJG19].

The current ALICA framework is limited to a predefined world-model (can be treated as a distributed Knowledge Base) and team set by the developer, and the type of information that is shared is predefined, i. e., the agents know what information they are expected to share and receive. This is suited for missions in dynamic but predictable environments, such as robotic soccer where the team is known and the rules are well defined [ABB+13]. Smart Cities are much more dynamic than a soccer game and unknown (i. e. not predefined) agents might enter the domain. Hence, having a predefined set of information that can be shared will not always work. As this research focuses on the domain of Smart Cities and S&R, especially during disasters, where parts of the critical infrastructure (Information and Communication Technology (ICT) or energy networks) of a city might be affected, ALICA needs to be extended to handle environments in which the considered information is changing dynamically. To do this, a Knowledge Base for the agents needs to be established so that the agents can reason about the state of the MAS and the environment and to plan activities.

The agents across the city could be robots, smart light poles, IoT sensors, etc. During emergencies, be it natural or man-made disasters, the agents single handedly can do very little in such complex and dynamic environments. However, when their information is brought together in a Knowledge Base, using reasoning, one can deduce multiple things about the state of the city and in turn help save as many lives as possible and return the city to normal working conditions as soon as possible. In order to benefit from all the agents and use their information wisely, Cloud and Edge based solutions for information storage, processing, and sharing need to be considered. As during emergencies the ICT infrastructure can be damaged and stressed, going for a Edge based approach is preferable as it can be distributedly set up and can reduce the latency in robot interactions. Furthermore, the software and hardware abstraction of each robot connected to the Cloud or Edge means that non-robotics experts can also develop programs without having to worry about the specific robots' architecture. With such solutions, it is possible to build a more dynamic world-model for ALICA which can then be used by the agents to cooperate efficiently and complete more complex tasks that they alone or as part of a small team cannot complete.

To implement such Cloud or Edge solutions it is beneficial to go with pre-existing Smart City platforms such as FIWARE[1] [UBG+13] and Sentilo[2], instead of custom solutions. FIWARE is an open source platform with extensive documentation that offers the NGSI (Next Generation Service Interface) API which provides high-level services for the development of services and applications for the city. FIWARE is able to represent context information based on the notation of entities using data models, exchange information with entities using a context data interface and exchange information on how to obtain context information using a context availability interface. The FIWARE platform integrates the Docker Generic Enabler [RMSE14, HJGH15] which offers the basic docker container hosting capabilities such as context management, connection to the IoT, creation of services and so on. Furthermore, FIWARE can be setup in Cloud-Edge configuration[3] which allows us to take advantage of the benefits of both technologies. With this,

[1] FIWARE: The Open Source Platform for Our Smart Digital Future; www.fiware.org; Accessed on 27.05.2021

[2] What is - Sentilo; www.sentilo.io/wordpress/sentilo-about-product/what-is/; Accessed on 27.05.2021

[3] Cloud-Edge Computing; https://fiware-tutorials.readthedocs.io/en/latest/edge-computing/index.html; Accessed on 27.05.2021

it is possible to extend the capabilities of agents to be able to receive and share information from the environment (context information) and collectively learn by sharing their trajectories, plans, outcomes, information and so on.
ALICA currently incorporates some aspects of collective robot learning, such as sharing plans, outcomes, information and goals, however this can be extended further to handle more dynamic environments. Adding the capabilities of FIWARE into ALICA will make ALICA more dynamic and hence more suitable for the target domains.

In this paper, Section 2 mentions the related work, Section 3 discusses the idea behind the project and the plan to extend ALICA and Section 4 concludes this short paper.

2 Related Work

The related work can be split into three categories. The first category consists of frameworks that are similar to ALICA. A comparison between these frameworks was done by Opfer et al. [OJJG19] and it was concluded that ALICA was the only framework that considers teams of agents and provides more features than the considered frameworks; however, it does not support changing behaviours at runtime. The second category is the Smart City platforms that exist and are currently in use. A survey of these platforms was published by Achilleos et al. [AMK+19]. While the majority of these platforms focus on Smart City solutions, FIWARE has a much wider use case as it has been used in a number of application domains such as IoT, robotics and smart homes [HJGH15], making it a perfect choice to be investigated further and incorporated into the ALICA framework. The final category is the use of Cloud computing in robotics. Many works in this field were mentioned by Herranz et al. [HJGH15]; however, their scope is limited to specific applications and therefore for highly dynamic environments these systems might not work as well. FIWARE is very dynamic and can deal with all types of information, hence the Knowledge Base can be comprehensive while also being distributed. The work done by Herranz et al. [HJGH15] shows how powerful FIWARE can be when integrated with the Robotic Operating System (ROS).

3 Solution Approach

In order to extend ALICA with FIWARE, some of the fundamentals need to be further developed, for example the information shared via the world-model is predefined. In a highly dynamic environment, we do not know all the information that should be shared, and the information that should be shared can differ when the state of the environment changes and therefore, a good starting step is to ensure that the information shared in the world-model is dynamic and depends on the state of the environment.
The existing ALICA framework[4] works in tandem with ROS, which implies that we can use any preexisting ROS packages. The work done by Herranz et al. [HJGH15] introduces the FIROS[5] package, which transforms ROS messages into NGSI-v2 to publish them into the Cloud and vice versa. The issue with the current integration is that it uses the outdated NGSI-v2 API rather than the NGSI-LD API, which supports linked data (entity relationships), property graphs, and

[4] newPD Branch; https://github.com/dasys-lab/alica; Accessed on 27.05.2021
[5] master Branch; https://github.com/iml130/firos; Accessed on 27.05.2021

semantics (exploiting the capabilities offered by JSON-LD). NGSI-LD ensures that the data obtained via FIWARE can be reasoned with to obtain the state of the MAS and the environment and to plan activities. Thus, the package needs to be adapted to use the new standard to make sure that the work is future proof and is able to be used with the new smart data models.

The first step (which has already been implemented) is to extend the world-model to add the agents and all the relevant information about them at run-time to the FIWARE context broker, this allows us to keep track of the agents and their information. The second step is to ensure that the predefined information from the world-model can be shared via the context broker. This step implies that the information shared by the agents need to be converted into NGSI-LD and then published into the context broker, and vice versa. The agents should keep their information up to date on the context broker when possible; however, they should avoid using the context broker for real-time communication if possible as it is not well suited for quick and efficient communication. However, some of this can be negated by using the Edge nodes. Currently, the agents can communicate with each other using the middle-ware Capnzero[6] or ROS messages, but other communication protocols can be implemented as well. When this step is completed, the basic infrastructure will be set up and the work on the dynamic information sharing in the world-model can begin.

The idea behind the dynamic information sharing is to ensure that the agents only share what is needed to complete the mission, this ensures that the network does not get overloaded. For example, let us assume that a task of a robotic agent is to follow another agent, the only information that needs to be shared is the location of the robot that should be followed; however, if the two agents are switched, the information that needs to be shared should also switch accordingly. This is important as it is vital to not overload the network with unnecessary information, especially during crisis which can affect the functionality of the communication network. After implementing the dynamic world-model the focus would turn to dynamically add, modify, and remove agents and teams.

4 Conclusion

This short paper has described the benefits of using Cloud and Edge based approaches in highly dynamic domains such as Smart Cities and S&R missions. Additionally, the emergence of MAS in Smart Cities and the need for a shared Knowledge Base for these agents is discussed. The presented solution approach describes the focus of the current research and what is planned for the future. In conclusion, extending ALICA to add the capabilities of FIWARE can make it more dynamic and thus applicable in many kinds of application domains. The idea presented has a promising future and can lead to many further interesting topics and research problems.

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[6] master Branch; https://github.com/dasys-lab/capnzero; Accessed on 27.05.2021

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