APRON: Adaptive Planning for RObotic Networks

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Preamble

This report describes the scientific research and the results obtained during the visiting period, from 20 August to 10 September 2013, for the Short Term Mobility program 2013, sponsored by the Italian National Research Council (CNR). The reported research was conducted by Dr. Donato Di Paola (CNR) in collaboration with Dr. Flavio Esposito (BU) and Prof. Abraham Matta (BU) at the Department of Computer Science of the Boston University (BU), Boston, USA.

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Introduction

The research presented in this report, is in the field of robotics and intelligent systems, in particular in the research area of robotic networks. Such networks are composed by a number of agents/robots possibly heterogeneous, *i.e.*, with a different set of skills, connected through a communication system and able to provide, in an autonomous way, a service or an application. In recent years, the possibilities of such systems have opened a lot of opportunities for applications. Typical examples of such applications are: urban mobility-on-demand systems, networks of robots for surveillance and environmental monitoring, and autonomous aerial vehicle systems to provide connectivity to ground stations. A common feature of these robotic-based networks applications is the ability to provide a particular service with continuity, *i.e.*, maintaining a high level of performance, and responding to events that may change the status of the network (e.g., damage to the agents or disconnections in the communication network). We define this type of service as a *persistent service*.

The main objective of this research is to study how the planning, *i.e.,* the procedure to assign tasks to the agents in the network, can affect the quality of the service provided. To pursue this goal, we proposed, designed and tested a novel Adaptive Planning for Robotic Networks (APRON) framework. APRON is able to add control functionalities to robotic networks in order to provide persistent services efficiently. APRON is based on an innovative planning methodology that, using a mathematical model of the network is able to control and react to the evolution of its states.

Problem Statement

In this report we consider robotic networks capable of acquiring data, to move in a given environment, and to communicate with other agents in the network. Each agent is able to execute a *task* with a certain degree of *quality*. The *quality* is a function of *internal events*, which influences the structural ability of the agent (in term of sensory equipment, computational power, and locomotion structure), and *external events*, which can occur in the environment such as presence of obstacles, meteorological events, and hazardous areas to be avoided. The objective of our APRON system is therefore to maximize the quality during the execution of the assigned tasks, even in the presence of perturbations in the structure of the agent or the environment.

A typical applicative example of such systems is the Dynamic Vehicle Routing (DVR) problem. In this application the tasks that robots have to perform correspond to locations in the environment to be visited within a given deadline. The objective of the DVR is to plan the paths of the robot so that all locations are visited, along the shortest route, while maximizing the number of locations visited before the deadline. This application is an example of *persistent service*, in which the network performance is maximized over time. The choice of a specific planning strategy affects in fact the quality of such (DVR) service, and determines its efficiency. The DVR problem was implemented as a case study of the APRON software simulator. This simulator is a novel Matlab toolbox, that allows users to compare various planning strategies to control the robotic network, and to run extensive simulations to evaluate the results of each proposed strategy.

Results

In the proposed research, we analyzed different strategies of planning over time in relation to events that occur to the network, changing its state. In the literature, we identify two different planning strategies: *proactive* and *reactive* planning.

The *proactive* planning is a time-driven approach: the planner module assigns tasks to the network after a fixed time interval. This technique does not require a monitoring nor an analysis of the data flowing through the robotic network or of the environment, thus the computational requirements are very light. Hence, in low-dynamic environments, i.e., where networks states change infrequently, the results are satisfactory. The main drawback of this technique is that, if the time interval is very narrow, the communication network will be overloaded.

R*eactive* planning strategies on the other hand are event-driven approaches. Typically, the planning is triggered by a specific change of the network state, such as a quality index lowering a given threshold. This approach provides overall quality improvement with respect to the proactive planning approaches since the network is able to react appropriately to changes in the environment, and minimizing also the traffic on the communication network. Reactive approaches however are not able to prevent the degradation of the quality and thus the planning is triggered when the event has already happened.

The contribution of this research is to find a trade-off between proactive and reactive strategies, proposing an adaptive planning method. This is obtained introducing a mathematical model of the network through which some parameters are estimated on the evolution of the task execution and the status of the individual agents. The planner changes the planning rate, anticipating the occurrence of events that would decrease the quality, using the parameters given by the model. Thus, the rate ranges from an arbitrarily large time interval, when the planning is not immediately needed, to small time intervals, when events that can degrade the quality level of the network are about to happen.

We also proposed an efficient model for the adaptive planning design problem. In particular, we leverage queuing systems theory to model a set of users (tasks) that are queued to get service from a server, before they leave the system. This model is used to estimate the load of the network in terms of the number of tasks in the queue. Once a number of required tasks is set, the tasks that the network can perform with a high level of quality are estimated, and such estimation is used to determine the planning rate.

Using such estimation of the tasks currently in the queue n and the target number of tasks n', a proportional controller has been designed, which reduces or increases the planning rate in proportion to the difference between these two values. Analytically the equation of such controller can be written as:

$K(n - n')$.

To corroborate the theoretical results obtained by the adaptive scheduling approach, based on the model of the queuing system, some simulations were performed within the APRON framework. Such simulations have shown a better behavior of the adaptive planning with respect to the proactive or reactive methods, thanks to the strategy of forecasting situations in which the quality of performance is affected by internal or external events, minimizing at the same time the traffic on the communication network.

In addition, using our adaptive approach it is possible to be resilient to permanent damages to the network. Such damages include elimination of one or more agents or links into forming the robot network. Such robustness is obtained re-assigning the tasks before failure events occur, reassigning the tasks only to agents with an higher level of quality.

Conclusion

In this report we summarized the research carried out at Boston University on planning methodologies for robotic networks. In particular, we proposed a quality-based model that allows monitoring the degree of persistency in a service provided by a robotic network during the execution of a set of tasks. Furthermore, we proposed an adaptive strategy for the task planning problem. Such strategy exploits the estimation of parameters based on a queuing system model. We plan to extend our work by studing decentralized approaches for the estimation of the parameters of our model and the design of a decentralized planner based on statistical learning techniques.