Making Networked Robots Connectivity-Aware

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***Abstract*— Maintaining the network connectivity in mobile Multi-Robot Systems (MRSs) is a key issue in many robotic applications. In our view, the solution to this problem consists of two main steps: *(i) making robots aware of the network connectivity; and (ii), making use of this knowledge to plan robots tasks without compromising connectivity*. In this paper, we view the ad-hoc network connectivity as an abstraction that is independent from application issues. We propose a new distributed algorithm executing on individual robots to build the connectivity-awareness. The correctness and theoretical analysis of the proposed algorithm are given. We also show how our solution allows checking network bi-connectivity more efficiently than existing work and can be used, for example, during distributed control motion.**

***Index Terms*— Mobile Ad Hoc Network, Multi-Robot Systems, Distributed Robot Motion Control, Dynamic Graph, Connectivity Maintenance.**

I. INTRODUCTION

The use of MRSs is promising in applications such as rescue operations after natural disasters. In such situations, a group of autonomous robots has to collaboratively perform a mission whose success depends on communication between individuals. Many studies have led to the conclusion that even the exchange of a small amount of information improves MRS performance for some tasks [1], [2].

In this paper, we are interested in communication between robots in a team relying on Mobile Ad Hoc Network (MANET) technologies [3]. Thanks to the underlying networking services, robots are able to detect some neighbourhood-related events (e.g. the appearance or disappearance of a neighbour), as well as to exchange messages with each others. Though useful, this information is not enough to enable robots to plan their motion while preserving their *network connectivity* during the mission. Among various aspects of MANET, research on routing protocols (which deals with the concern of how to route the data between a source and a destination in a MANET efficiently) has been one of the most active research domain for years. A routing protocol is responsible for finding a route provided that such a route does exist. However, it does not make robots aware of the global connectivity.

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In our vision, solution for this problem should be separated in two main steps: *(i) making robots acquire sufficient knowledge of the network connectivity; and (ii), exploiting this knowledge in order to best maintain the network connectivity while performing other tasks*. We further argue that the first step can be viewed as an application-independent abstraction. That is, the awareness of the network connectivity should be provided to robots as a basic networking service like routing in MANETs for example.

With respect to the first step, we present our proposed solution for making autonomous robots aware of the network connectivity in the following. The rest of the paper is organized as follow. In Section II, we present some definitions about graph theory in the context of MRS. Section III introduces a new distributed algorithm in order to enable each robot to build and maintain an *awareness* of the network connectivity. Based on this awareness, robots are individually able to perform actions that help them achieve the mission's goal without breaking the network connectivity. In Sections IV and V, we use our algorithm for checking biconnectivity and for distributed motion control. Section VI presents related works. Section VII concludes the paper.

II. PRELIMINARIES AND DEFINITIONS

We model a system of networked robots by an *undirected* graph $G = (V, E)$, where V is the set of robots in the network, $E = V \times V$. There is an edge $e = \{R_i, R_j\} \in E$ if and only if R_i and R_j can *mutually* receive each other's transmission, i.e. the link between them is bidirectional. In this case, we say R_i and R_j are neighbours, and the edge is also referred as a *communication link* between the two robots. The number of neighbours[1] of a robot R_i is denoted by d_i, and $\bar{d} = \frac{\sum_i d_i}{n}$ is the average number of neighbours, where n is the number of robots ($n = \mid V \mid$). These notions are used throughout in the paper. Note that the graph can change in time as nodes are moving.

Definition 1 (Communication path): In the graph G, a *loop-free* sequence of nodes taking part in the process of relaying data from R_i to R_j or symmetrically from R_j to R_i is called a *communication path* $p(R_i, R_j)$ (or simply a path hereafter).

[1]For the graph G, d is also called the degree of a vertex.