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Boundary and holes recognition in wireless sensor networks

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HIGHLIGHTS

- We introduce a novel force scheme for master–slave setups operating under a delayed/lossy network.
- The scheme reduces position errors at the slave end-effector, caused by the delay and packet loss.
- We experimentally validate effectiveness of the scheme by testing on a teleoperated hydraulic manipulator.
- Addition of the proposed scheme, for the cases tested, could reduce tracking errors up to 92%.
- We detect significant difference between slave position errors with and without the force scheme.

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ABSTRACT

In this paper, a distributed solution is proposed for detecting boundaries and holes in the WSN using only the nodes connectivity information. The run of our protocol is divided imto three main steps. In the first step, each node collects connectivity information of its one-hop neighbors and constructs its one-hop neighbors' graph. In the second step, independent sets are constructed. In the last step, the independent sets are connected in order to find the closed path. Therefore, the node can make its own decision to be an internal or a boundary node. Simulation results show that our algorithm can detect fine-grained boundaries with high accuracy, low energy consumption and less communication overhead compared to some former works. In addition, this algorithm performs better than some exiting approaches (BCP, THD, and SDBR).

1. Introduction

Due to the random deployment of sensor nodes, nodes' failure, or an environmental obstacle (building, lake . . .) holes can be formed in the network, creating sets of isolated nodes and leaving uncovered areas. Moreover, they can also cause the failure of routing algorithms. Once detecting either the nodes on the boundaries of holes or on the network's boundary; uncovered areas will be detected and could be repaired by an incremental addition of new sensors, the aforementioned detection also allows the routing protocols to identify and pass these holes [1].

The existing boundary detection algorithms can be classified into three main categories according to their used

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techniques: geometrical methods, statistical methods and topological methods. Each category has its advantage and its weaknesses.

This paper aims to provide a simple and efficient distributed approach to discover the boundary nodes in the network. We distinguish two types of boundary nodes: the internal boundary nodes that surround the holes and the outer boundary nodes, which lie on the external boundary of the sensing field [2]. Regarding their small size, low cost and limited energy, most of the sensors are not equipped with a positioning device. Therefore, we rely solely on the topology extracted from the available connectivity information.

The run of our Boundary Detection protocol based on Connected Independent Sets (BDCIS) is divided in three main steps. In the first step, each node collects connectivity information of its one-hop neighbors and constructs its one-hop neighbors' graph. In the second step, independent sets of cardinality α are established. In the last step, the independent sets are connected in order to search for the closed path. Therefore, each node can make its own decision to be internal or boundary node.

The rest of this paper is organized as follows:
Section 2 gives an overview of some existing boundary detection algorithms. Section 3 presents our alternative solution for the stated problem. Simulations and performances' analysis are given in Section 4. Finally, Section 5 concludes the paper and brings some future perspectives.

2. Related work

The existing boundary detection algorithms can be classified into three main categories according to their techniques: geometrical methods, statistical methods and topological methods [3].

Geometrical methods assume that nodes are aware of their geographical positions by using GPS or other positioning device. These methods can find boundaries with high accuracy and less control messages.

Fang et al. [4] studied a fundamental problem behind the "local minimum phenomenon" in geographic forwarding. They defined the stuck nodes where packets can possibly get stuck in greedy multi-hop forwarding, and developed a local rule, the TENT rule, for each node in the network to test if it is a stuck node. To help packets get out of the stuck nodes, they developed a distributed algorithm, BOUNDHOLE, to find the so-called holes, the regions of the network with boundaries consisting of all the stuck nodes. Holes are usually associated with regions where nodes are depleted or regions that do not have enough nodes due to irregular terrain. Holes have sometimes been referred to as "communication voids" as well. Both their analysis and simulations show that the holes identified using this method indeed capture the underlying structure of the network and correctly identify regions with communication voids. Another centralized algorithm proposed in [4], which is based on Restricted Delaunay Graph (RDG). Hole is defined to be a face in the RDG with at least four vertices.

Sahoo et al. [5] proposed sequential and distributed boundary nodes selection SBNS and DBNS algorithms. The SBNS algorithm assumes the sink to be a boundary node then uses the right hand rule to select boundary nodes in a sequential manner. The process is lunched by the sink and is repeated until the starting node (sink) is revisited. The DBNS algorithm defines extreme nodes as boundary nodes then connecting them to form cycles enclosing boundaries. An extreme node is defined as a node that has either maximum or minimum value in its coordinates compared to of its one-hop neighbors. The main drawback of these methods is the need of an accurate coordinates of sensor nodes. Each node must be equipped with a positioning device such as GPS to obtain its geographical location, which is not suitable for small sensors with low energy consumption.

Fekete et al. [6] described a new approach for dealing with the central problem in the self-organization of a geometric sensor network: given a polygonal region R, and a large, dense set of sensor nodes that are scattered uniformly at random in R. There is no central control unit, and nodes can only communicate locally by wireless radio to all other nodes that are within communication radius r, without knowing their coordinates or distances to other nodes. The objective is to develop a simple distributed protocol that allows nodes to identify themselves as being located near the boundary of R and form connected pieces of the boundary. They gived a comparison of several centrality measures commonly used in the analysis of social networks and show that restricted stress centrality is particularly suited for geometric networks; they provided mathematical as well as experimental evidence for the quality of this measure. Fekete et al. [7] also proposed another boundary detection algorithm called Connectivity-based Distributed Coverage Hole Detection CDCHD. The basic idea is that nodes on the boundaries have relatively smaller average degrees than nodes inside the network. A statistical threshold is used to distinguish between boundary nodes and internal nodes.

Statistical methods assume that the distribution of nodes within the network follows some statistical properties.

Destino [8] suggested a centralized algorithm Boundary Recognition via Graph-Theory (BRGT) based on a graph clustering technique, which allows the division of the network into small cells (clusters) that circumvent connection holes. Then, the boundary nodes of each cluster are identified using centrality scores. The detection of boundary nodes is performed by the fusion of adjacent clusters. Only nodes that are on the border of a single cluster and are not connected to two or more clusters are selected as boundary nodes. The algorithm is centralized and the entire network topology must be collected by the base station to begin the discovery process, which is not suitable for large sensor networks.

A Topological Hole Detection (THD) algorithm based on the idea of using the iso-contours was introduced by Funke [9]. After choosing four beacons, the nodes having the same hop count from a beacon should belong to the same contour. These contours are broken into connected components due to the presence of holes or when they meet the outer boundary. For each connected component, a local beacon is chosen and the computing of shortest distance from this beacon is performed. The nodes with highest distance values must lie on both 'ends' of each connected component. These nodes are marked as boundary nodes. This

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