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A joint routing and localization algorithm for emergency scenario

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ABSTRACT

Wireless Sensor Networks (WSNs) have been adopted in a wide range of industrial and consumer applications such as environmental or industrial monitoring, health control, or military systems, for a decade. Main issues in WSN are represented by the large number of sensor nodes, multi-hop communication approach, and needs for an efficient use of available limited sensor energy. In this work an emergency scenario is considered and a WSN is used as a communication infrastructure. To limit the power consumption, the WSN is activated only when the emergency occurs. Few mobile nodes (the rescuers) are moving in the area.

In these critical network scenarios, adaptive routing is essential to ensure reliable communication with first responders. At the same time, localizing both WSN nodes and moving nodes is an essential issue for routing the rescuers towards victims. In this paper, the authors jointly tackle routing and localization problems for reducing the network signaling communication as much as possible, which is the most power-consuming operation in WSNs. In particular, it is proposed a distributed localization algorithm, based on a ranging technique, designed by mapping the localization into a stochastic estimation problem for systems with uncertainties.

1. Introduction

Recent advances in wireless communication and electronics allowed the development of low cost, low power, and multi-functional WSNs. A WSN is a set of spatially distributed autonomous sensors that can be used for monitoring physical or environmental parameters, such as temperature, humidity, vibration, pressure, motion, or pollution. The size of each sensor is related to the particular application, ranging from the size of a box (e.g., a weather station) to microscopic dimensions (e.g., when used in military applications). Since sensor nodes are unattended autonomous devices, their energy, computing, storage, and communication capabilities are limited by size and cost constraints. Initially deployed for military applications, such as battlefield surveillance, today WSN are used in many different fields for both industrial and civil purposes. Recently, many authors have suggested their application to emergency scenarios.

In these situations, the pre-existing communication infrastructure, as well as the mobile public communication network, could be partially damaged. During the initial rescuing phase, first responders need to locate themselves, with respect to the unknown scenario so as to reach the main emergency area for saving injured people. In other words, the ability of localizing every first responder, with respect to the environment, can determine the success of rescue operations.

Nowadays, most of existing techniques for managing first responders during crisis are based on simple practices supported by heavy training. Many research activities have been carried out to enhance the ability of first responders to react to and recover from incidents with well-coordinated efforts. They focus on novel techniques for accurately locating the entities (or nodes) with respect to a global coordinate system. In this framework, the National

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Institute of Science and Technology (NIST) suggested the adoption of pre-emergency deployed WSN, for correlating sensor readings with physical locations [32].

The simplest mechanism for determining the sensor node position is the Global Positioning System (GPS). However, its application to emergency WSN is often unsuitable for the following reasons: since it is based on an extensive infrastructure it requires the visibility of the satellite constellation and therefore cannot be used indoor. Hence WSNs localization has drawn considerable attention and several approaches have been proposed. The main issues in WSN localization are analyzed in [31].

The emergency scenario presents two main constraints: the capability of handling a large number of unattended autonomous nodes and the adaptability to environment and task dynamics. At the moment, the scalability and adaptability issues are still far to be completely solved in WSN. Another key factor in emergency WSN is the energy consumption. Sensor nodes do almost always operate on battery and are rarely equipped with solar energy panels. Therefore, optimal energy consumption is mandatory: it is often impossible to recharge or replace the energy-depleted nodes because of the desolate or harsh environment of the target area. Since most of the energy budget in a node is spent for transmission and reception of the acquired data, reducing traffic overhead for network setup becomes fundamental.

In this work the authors deal with a large emergency area or with a deep indoor scenario. To minimize the system energy consumption, a clustering based routing and localization algorithm is here presented. It is supposed that, in the operating area, a WSN has already been deployed and that it can be activated in case of emergency. Some of the nodes (anchors) are able to localize themselves by means of an absolute positioning system. During the network start-up, the network infrastructure is created. To reduce the network overhead, multi-step routing and localization protocols are adopted. In the first phase, nodes are collected into clusters. Afterwards, a coarse-to-fine approach is exploited: the output of the routing protocol provides an initial guess about the node positions that will be refined by the localization procedure. The main novelty of the approach relies on the use of joint localization and routing protocols: indeed, localization and routing are regarded, in literature, as separated problem, as pointed out in Section 2.

The main contributions of this work are the design of a cluster based routing and localization algorithm and the design of a distributed localization algorithm, based on ranging technique. Here, localization is mapped into a stochastic estimation problem for systems with uncertainties. More in detail, the proposed procedure exploits the benefits of Cluster Based Routing Protocol (CBRP) [22], Luby algorithm [30] and Extended Kalman Filter (EKF) [16]. Both routing and localization are solved according to a fully distributed and decentralized approach. The overall system is self-organizing (i.e., it does not depend on global infrastructure), robust (i.e., it is robust vs node failures and range errors), and energy efficient (i.e., it has low computational complexity and communication overhead).

It is useful to point out that the proposed solution is not unique to humanitarian relief. A generally adopted definition for humanitarian relief is the provision of life-saving assistance to those in need, including victims of conflicts and natural disasters. Humanitarian relief is related to a very broad research and action area. The paper's goal is to improve the efficiency of emergency response system: during crisis, the availability of the pre-deployed communication infrastructure is not guaranteed, therefore the automatic reconfiguration of *survived* communication system is mandatory.

The remainder of the paper is organized as follows: In Section 2 the state of the art on routing and localization in WSN is presented. In Section 3, the main features of the WSN for emergency scenario are detailed and the problem setting is defined. Section 4 is dedicated to the description of the two selected clustering techniques while in Section 5 the distributed localization algorithm is defined. In Section 6 the proposed joint routing and localization procedure is detailed. Simulation results verifying the effectiveness of the proposed approach are presented in Section 7. Finally, concluding remarks and future works are drawn in Section 8.

2. Related work

Localization allows each node to compute its geographical position with acceptable accuracy. Although localization is not the main objective of a WSN, it turns out to be fundamental in many applications such as wild-fire monitoring [27], smart farming/harvesting [5], habitat monitoring [33], structural health monitoring [21], surveillance [20], and emergency response systems [28,14]. During crisis, localization becomes mandatory to identify the position of both rescuers and victims. To this end, an unsupervised, self-localizing procedure is needed in WSNs able to set up a virtual network infrastructure to support cooperation among nodes.

In a WSN, the data communication and positioning protocols are important mutually interacting techniques. Usually, when addressing localization, an existing network infrastructure is supposed to be available, while when dealing with routing, the network infrastructure is setup without localization information or, as in geographical routing, assuming that nodes are able to self-localize. Although the research on localization algorithms and routing protocols for wireless sensor networks has been extensive, to the best of our knowledge these two research topics have been studied separately: only few works deal with simultaneous routing and localization [35]. In the following, the relevant literature in the two areas and the efforts towards the joint analysis are reviewed.

The basic functionality of routing in an ad hoc network is to relay data using multi-hop communication model. Routing protocols in wireless multi-hop networks can be categorized into reactive, proactive, and position-based approaches. In proactive routing, all nodes maintain a consistent map of the network topology by computing the routing tables in advance. Therefore, the node can start communicating immediately after a data request. The