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Energy-aware sensor node relocation in mobile sensor networks

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ABSTRACT

We propose a sensor node relocation approach in wireless sensor networks to maintain connectivity between a Region Of Interest (ROI) where the sensor nodes are initially deployed and a Center Of Interest (COI) outside the ROI where a particular event happens. Our proposed approach, called Chain Based Relocation Approach (CBRA), aims to relocate a minimum number of redundant sensors from their initial positions within the ROI towards the COI to maintain the connectivity between the ROI and the COI. CBRA uses steps which determine the redundant nodes' set, the propagation of the COI coordinates within the ROI and then the selection and the relocation of the redundant nodes towards the COI. The selection of the redundant nodes is based on an average energy consumption model to balance the energy consumption among the sensor nodes when they are relocated depending on their initial and final positions. We evaluate the performance of CBRA using performance metrics such as energy consumption, the number of relocated nodes, relocation time and number of transmitted messages. Sensor nodes are relocated using a chain-based method between the ROI and the COI. In addition, if one relocated sensor node fails, the connectivity between the COI and the ROI is affected. To address this possible failure, we propose a fault tolerant recovery procedure to repair the route between the COI and the ROI. Finally, we compare the performance of CBRA with two other approaches.

1. Introduction

Wireless sensor nodes are low cost, low power small devices being used in a wide variety applications such as military surveillance, health monitoring, and environmental monitoring to capture different kinds of events and sending the captured data through multi-hop communications to the "sink node(s)" for processing.

Mobile sensor networks become increasingly used as the reference technology in the wireless communication field. For instance, using mobile sensor nodes in WSNs allows preventing variety of problems in these networks such as node failure, communication breakage, and coverage holes using self organization and self-deployment techniques [20,31,17].

Indeed, initially conceived as low cost and low power small devices, sensor nodes allowed the expansion of the wireless sensor networks (WSNs) in different applications fields (military, surveillance, e-health, etc.). The expansion of such networks is due to their facility of deployment. For instance, sensor nodes can be wiped in places where human intervention is impossible. Moreover, being equipped with individual energy resource, sensor nodes can cooperate together to work in an autonomous manner. Some problems, however, can occur within the network which may disturb its correct functioning. At that time, using sensor nodes equipped with mobility modules will allow solving problems encountered by the WSN and that may disturb its correct functioning. For instance, mobile sensor nodes can be used either to avoid coverage holes, or to ensure both coverage and connectivity within the network. Moreover, they can also be used to ensure fault tolerance within the network by recovering from broken

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network links or preventing/recovering from node failures [18,14,30,19,15]. Other research efforts use mobile sensor nodes to improve the network performance by maximizing the network lifetime [16]. In all the above mentioned cases, mobile sensor nodes are used to solve problems happening within the zone where the sensor nodes were initially wiped.

It is worth pointing out that the problem we address in this paper is slightly different from other sensor mobility approaches because the sensor node relocation approach we propose in this work relocates some of the sensor nodes outside of the their initial deployment zone called Region Of Interest (ROI) to cover an event outside the ROI called the Center Of Interest (COI). For example, if a chemical spill disaster occurs in a chemical plant, the dangerous substances may flow outside of the initial area of the chemical plant already controlled by a wireless sensor network. In this case, we may need to measure the degree of soil contamination at a given point outside the initial zone, and we would probably need to relocate some of the sensor nodes to that COI to report relevant information to the sink node. Hence, the relocation of such nodes must take into consideration the fact that the network within the ROI must continue to function correctly despite the movement of some sensor nodes outside the ROI. Moreover, the sensor nodes relocation approach needs to maintain the communication between the ROI and the COI so that the new captured data could be transferred to the sink node for processing. To ensure coverage/connectivity within the ROI, we need first to determine the minimum number of sensors that can guarantee the full coverage. The rest of the nodes known as "redundant nodes" can therefore be used for other purposes. Then, as stated in [32], a necessary and sufficient condition for coverage implies connectivity in a sensor network is given by the following condition $R_c \geqslant 2R_s$ (where R_c is the communication range and R_s is the sensing range).

Hence, in this work we propose a new approach called Chain Based Relocation Approach (CBRA) which aims to relocate a minimum number of sensor nodes towards the COI while ensuring the connectivity between the COI and the ROI. Moreover, the main goal of CBRA is to reduce the energy consumption caused by the sensor nodes relocation. This is achieved using an analytical model that estimates the average energy consumed by the mobile nodes if they were relocated towards the COI. Then the selection of the nodes that will be effectively moved to the COI is done using the energy estimation deduced from the analytical model. The CBRA approach was initially proposed in [3]. In this paper, we extend the simulation results presented in [3] by considering additional performance metrics. We also propose a new fault tolerance procedure to ensure recovering from errors. For instance, as CBRA ensures relocating a minimum number of nodes towards the COI, then the failure of one node along the path relating the COI to the ROI causes the loose of connectivity between the two zones. Moreover, we propose in the last part of the paper to compare the CBRA to another relocation technique known as the virtual subgrid approach [4] to show that CBRA offers better performance results than the virtual subgrid approach.

The remainder of the paper is organized as follows. In Section 2, we present related works on sensor node relocation and our contributions. Sections 3 and 4 describe the different procedures introduced by CBRA to cover an event happening outside the ROI. In Section 5, we evaluate the performance of our proposed approach using performance metrics such as the number of exchanged messages, the whole network energy consumption and the relocation time. In Section 6, we present the fault tolerant mechanism that allows to repair the route between the COI and the ROI after a sensor node failure. In Section 7, we compare the performance of CBRA with two other sensor node relocation approaches namely, the native grid quorum [30] and the virtual subgrid approach we proposed in our previous work in [4]. Finally, we make some concluding remarks and present future works in Section 8.

2. Related works and contributions of this work

2.1. Related works

Sensor node relocation appeared early on as one of the most important issues in wireless sensor networks. For instance, initially conceived for fixed networks, the sensor nodes' mobility quickly emerged as a promising solution to a variety of problems (such as nodes' failure, coverage holes, broken links, and energy resource depletion) associated with WSNs. In early WSNs, equipping sensor nodes with mobility modules was very expensive. Therefore robots have been used either as replacing nodes to repair/prevent the nodes' failure in the networks [11,27,2] or as carriers to place sensors in vulnerable places where nodes fail and coverage holes or connectivity breakage occur in the network [6,29,10,7]. Thank to cheapness of mobile sensor devices, it becomes possible to have some/all the nodes within the network equipped with mobility modules. Relocating mobile sensors in WSNs can be done for different purposes: to heal coverage holes, to perform network resource optimization or for fault tolerance purposes.

2.1.1. Mobile sensor nodes relocation to heal coverage holes

After the initial deployment of the sensor network, some regions in the network may remain uncovered due to the random deployment of sensor nodes. By using mobile sensors, the uncovered network zones can be repaired by relocating nodes to these zones.

For instance, in [25,26], the authors consider a multi-layer *k*-coverage scheme within an area of interest. Indeed, they divide their problem into two sub-problems: a placement problem where the minimum number of sensor nodes and their positions are determined to ensure the *k*-coverage of the area of interest and a dispatch problem where mobile sensors need to move to the positions computed by the placement problem so as to minimize the energy consumption caused by the movement. In [35], the authors propose a sensor nodes' relocation scheme based on virtual forces. Sensor nodes behave as sources of potential forces. If two sensors are too close to each other, they exert a repulsive force and move away from each other. However, if the sensors are too far from