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Hybrid movement strategy in self-orienting directional sensor networks ☆

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ABSTRACT

The coverage problem in directional sensor networks (DSNs) introduces new challenges especially for randomly deployed networks. As many overlapped regions and coverage holes might occur after the initial deployment, self-orientation of the nodes is a necessity for randomly deployed DSNs. There exist two main approaches for the self-orientation of directional sensor nodes in DSNs [1], *motility* and *mobility*. Motility refers to the adjustment of the working direction of the nodes, whereas mobility describes the physical movement of the nodes. Most existing studies propose solutions based on the motility capability of the directional sensor nodes. On the other hand, mobility is a powerful feature offering great flexibility. Nevertheless, the high energy consumption of mobility discourages researchers to utilize this approach in their solutions. In this study, we propose a novel approach, a hybrid movement strategy (HMS), where we exploit motility/mobility in a cascaded manner for the coverage improvement in DSNs. The HMS improves the initial coverage up to 47% and achieves up to 7% more coverage than the motility only solution. Besides, it has provided at least 40% energy-saving compared to the mobility only solution in our scenarios.

1. Introduction

The coverage problem is a fundamental problem in sensor networks [3,4], especially after random deployment. The research community has thoroughly explored this problem for omni-directional sensor networks [5,6]. Proposed solutions basically depend on two principles: *redeployment of additional nodes* and *use of mobile sensors*. On the other hand, a new network type, the so called "Directional Sensor Network" became popular within the last five years and brought new challenges to the traditional coverage problem [1,7,8]. Directional sensor networks typically consist of nodes equipped with direction-sensitive video, infrared and/or ultrasound sensors. A directional sensor node has a sectoral perception within its sensing radius. Thus, a node could work in several directions around itself. The adjustment capability of the working direction of a directional sensor is called as *motility*. Random deployment in DSNs mostly results in several overlapped regions, therefore, directional sensor nodes need to be repositioned after their initial deployment in order to increase the total area coverage. In DSNs, the utilization of motility is the most energy-efficient way to minimize the overlapped regions and to cover some coverage holes, since motility does not cause the node to change its physical location. Thus, a great number of existing solutions exploit this motility capability for the coverage problem [9–12].

Although, the efficiency of a DSN heavily depends on the correct working direction of its individual sensory units in the field, motility could not be sufficient enough in some scenarios. At this point, mobility capability of a sensor node offers a great advantage to decrease existing overlapped areas and to prevent coverage holes [2].

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However, exploiting mobility alone is a highly expensive solution compared to motility. Thus, we propose a hybrid movement strategy (HMS) for the coverage problem in DSNs, where both motility and mobility are utilized in a cascaded manner. In the HMS, we first exploit the motility capability of the nodes to minimize the overlapping regions without moving the nodes to a different location. With appropriate working directions of the nodes determined, if there exist overlapped regions and coverage holes, we engage the mobility capability in our solution. Thus, in this study, a new coverage enhancement model, hybrid movement strategy, has been introduced in order to maximize the coverage after the initial deployment in an energy-efficient way. The key contributions of this paper are given as follows,

- To demonstrate the efficiency of the HMS, we exploit three novel algorithms for both motility and mobility parts of the proposed solution. Two novel algorithms, the Attractive Forces of Uncovered Points (AFUP) [13] and the weighted AFUP (W-AFUP) [14], are implemented for utilizing the motility capability. Besides, one unique algorithm, Window-based Neighborhood Exploring (WNE), has been introduced in order to exploit the mobility capability. The proposed algorithms run fully distributed using local information only, thus, communication overhead is incurred only between neighboring nodes. We also introduce Motility Assisted Mobility (MAM) algorithm, a particular implementation of the HMS, where motility and mobility parts of the algorithm consist of the W-AFUP and the WNE algorithms respectively.
- Though AFUP and W-AFUP outperforms several existing solutions [15–17] based on the motility capability, we show that motility could improve the total coverage up to a limit. Especially for dense networks, we demonstrate that the total area coverage could be improved further by exploiting mobility.
- We also show that exploiting the mobility alone is highly expensive than the HMS, in terms of the number of moved nodes, total travel distance and energy consumption. The HMS achieves in maximizing the area coverage with possible minimum energy by combining the advantages of motility and mobility.

The remainder of the paper is organized as follows. In Section 2, we discuss the available studies about directional coverage problem in DSNs. Section 3 gives the notations and definitions to the area coverage problem. In Section 4, we present our new coverage enhancement model, hybrid movement strategy and explain the details of the proposed AFUP, W-AFUP and WNE algorithms. AFUP and W-AFUP utilize the motility capability, whereas WNE exploits the mobility capability. In Section 5, experimental results are given in detail. The results demonstrate that the HMS could improve the total coverage much more than a motility only solution. Moreover, it achieves this improvement in an energy-efficient way compared to the mobility only solution. Section 6 concludes the paper.

2. Related work

Maintaining and maximizing sensing coverage of scattered sensor nodes have been studied in great depth in traditional sensor networks for the past decade [5]. Available studies aim at covering a plane by arranging circles on the plane. However, the proposed solutions for omni-directional coverage cannot be used for the coverage of direction-sensitive nodes, since these nodes capture only a predefined sector within their sensing radius according to their angle of view and working direction. This predefined sector is described as the *Field-of-View (FoV)* of a node. Especially after random deployment, some FoVs might overlap in the observed area. Besides, some targets might be left uncovered. To overcome these difficulties, researchers opt for the *motility* capability of directional sensors. On the other hand, to the best of our knowledge, only one study [18] proposes to utilize the *mobility* capability of directional nodes. However, in this study, the authors do not take the motility capability into account and they do not change the working directions of the nodes.

In [1], we have described the directionality problem in DSNs and surveyed existing solutions to the coverage problem. Available studies could be categorized into four groups.

- Target-based coverage enhancement solutions.
- Area-based coverage enhancement solutions.
- Coverage enhancement with guaranteed connectivity.
- Network lifetime prolonging solutions.

Some sensor applications are only interested in stationary target points, such as buildings, doors, flags, and boxes, whereas other applications aim at tracking mobile targets like intruders. Stationary targets can be located anywhere in the observed area. To cover only the interested targets instead of the whole area, researchers have defined target-based coverage problems. Unlike the area coverage, this issue puts emphasis on how to cover the maximum number of targets. Several solutions have been presented for target-based coverage enhancement [19–21]. On the other hand, enhancing area coverage is an very important issue for DSNs to fulfill the specified sensing tasks. The objective is to achieve maximal sensing region with a finite number of sensors. As we aim at maximizing the area coverage, we will discuss only the area-based coverage enhancement solutions in details.

Since a small unmonitored sub-area defeats the whole purpose of the network, sensor nodes need to be spread as uniformly as possible over the entire sensing region with minimum gaps. However, random deployment may cause several problems, such as overlapped and occluded regions, uncovered areas, and broken sensor nodes. Therefore, three basic (well-known) principles have been utilized by the research community to overcome these difficulties. First approach is based on the redeployment of new sensors after the initial deployment. This approach has taken too little interest due to its several drawbacks. For instance, deploying additional nodes to the estimated positions is extremely difficult. Thus, in the monitored